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STAND STRUCTURE AND PATTERNS  
OF CONIFER REGENERATION  
NEAR COLSTRIP, MONTANA

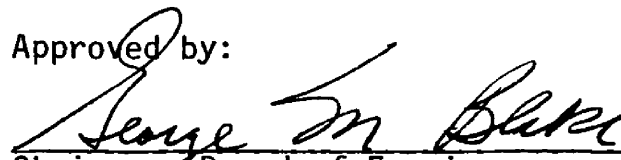
By

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B.S., North Dakota State University, 1977

Presented in partial fulfillment of the requirements for the degree of  
Master of Science  
UNIVERSITY OF MONTANA  
1981

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Forestry

Stand Structure and Patterns of Conifer Regeneration near  
Colstrip, Montana (122 pp.)

Director: Dr. George M. Blake



The purpose of this study was to 1) provide baseline information on conifer regeneration and stand development near Colstrip, Montana, and 2) to apply this information toward reclaiming strip mined lands. Two coniferous species occur near Colstrip: ponderosa pine (*Pinus ponderosa* Laws. var. *scopulorum*) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). Tree and seedling plots were sampled along north-facing and south-facing transects in twelve stands. Stands were all-aged and were composed of pine or mixed pine and juniper. Tree density ranged from 59 stems/ha. to 1447 stems/ha. and was greater on north-facing slopes. Fire frequency ranged from 0 fires/103 years/1.5 ha. to 8 fires/150 years/1.0 ha. Seedling density varied directly with basal area and inversely with potential radiation, bare mineral soil and calcareousness. Eighty-nine percent of the pine seedlings and all juniper seedlings received partial shade. The highest height/age ratios occurred in deep, rocky, sandy-textured soils. Low density regeneration occurs every year in favorable microsites.

## ACKNOWLEDGEMENTS

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## INTRODUCTION

The federal Surface Mining Control and Reclamation Act of 1977 and Montana's Strip and Underground Mine Reclamation Act of 1977 require the re-establishment of permanent, diverse, self-regenerating vegetative cover on regraded mine soils. Reclaimed acreages must have vegetative cover composed of at least fifty percent native species and woody species must have comparable stocking levels to unmined areas.

Two woody tree species dominate upland areas near Colstrip: ponderosa pine (*Pinus ponderosa* Laws. var. *scopulorum*) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). Problems associated with conifer establishment on mine soils differ from problems associated with herbaceous species establishment. First, both tree species are largely limited to broken, rocky topographic positions in the western Great Plains (Wells 1970). Regraded soils are rarely as steep and often lack substantial rock components. Second, pines and junipers do not become reproductively mature until they are 15 to 20 years old, therefore several decades will be required to determine whether they successfully self-regenerate on mined lands.

Researchers with the Montana Agricultural Experiment Station (MAES) have attempted to establish pines on mined lands near Colstrip. Although their experiments were only partly successful the following conclusions were made: 1) containerized stock was preferable to bare-root stock, 2) straw mulch reduced seedling mortality for the first

two seasons, 3) transplanted saplings may be an effective means of establishment (DePuit *et al.* 1978) and 4) direct seeding on scoria fill resulted in low density but vigorous seedlings (Sindelar *et al.* 1973). MAES studies resulted in severe mortality in ponderosa pines, thus further studies were begun in 1979 at the University of Montana.

This study, one of several currently in progress at the School of Forestry, University of Montana, focuses on the stand structure and patterns of regeneration in natural coniferous stands near Colstrip. Stand structure essentially records the interactions between natural regeneration, time, climate, parent material, organisms, relief and fire. By understanding the dynamics of natural regeneration we can better prioritize cultural treatments to insure successful establishment and long-term self-regeneration on mined lands.

The specific objectives of the study were as follows:

1. Determine age-class (ponderosa pine) or diameter-class (juniper) structure of natural upland pine and mixed pine/juniper stands near Colstrip to show temporal patterns of regeneration.
2. Present structure, density and basal area summaries for sample stands
  - a. Determine whether age-class data (i.e., previous periods of previous establishment) correlate to fire and climatic history.
  - b. Test for differences in stand structure on north- versus south-facing aspects.

- c. Compare relative productivity of stands.
- 3. Record microsite conditions (radiation loads, surface rockiness, bare mineral soil, competition) under which ponderosa pine and juniper are establishing.

## GEOLOGY

Ponderosa pine and Rocky Mountain juniper near Colstrip are closely associated with outcrops of the Tongue River member of the Fort Union Formation. The Tongue River member, the youngest of three members in the Fort Union Formation, contains sandstones, shales, siltstones, clays, coal, and porcelanite. Underlying the Tongue River member are the Libo shale and Tullock members which outcrop more frequently toward the confluence of Armell's Creek and the Yellowstone River north of Colstrip.

The deposition of the Fort Union Formation in the Paleocene (60 million years B.P.) was closely associated with the Laramide orogeny which began to form the Rocky Mountains in the late Cretaceous (100 million years B.P.). Fort Union fossil remains indicate that the Great Plains supported marshy, forested vegetation in the Paleocene.<sup>1</sup> As the Rocky Mountains continued to uplift, sediments were periodically deposited in the western Great Plains (Perry 1962); concomitantly, subsidence was occurring in the Powder River Basin (Curry

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<sup>1</sup> Brown (1952) and Spindel (1975) cite numerous taxa including *Meta-sequoia occidentalis*, *Sequoia* spp., *Corylus* spp., *Viburnum antiquum*, *Alnus* spp., *Salix* spp., and many other broad-leaved dicotyledons.

1971). The numerous coal beds in southeastern Montana suggest that the Paleocene was relatively stable for long periods of time between major depositional phases. Howard (1960) suggested that the change to a more arid climate following the Paleocene and early Eocene was due to the eventual obstruction of moisture-laden westerlies.

Deposition in eastern Montana continued into the Oligocene (White River formation) but deposits of this age have eroded from southeastern Montana (Howard 1960). Howard (1960) stated that since the Oligocene (ca. 30 million years ago) the northern Great Plains have undergone degradation. Uplifting at the close of the Cenozoic era which increased downcutting by streams, and the reworking of major drainage systems during the Pleistocene shaped the current landscape near Colstrip (Pierce 1936). Continental glaciers did not advance into the area. Gradual erosion has continued to the present.

A distinctive feature of the landscape around Colstrip is the brightly colored "scoria" or porcelanite<sup>2</sup> which forms a resistant cap-rock above steeply eroding slopes. Porcelanite forms from clay, shale, or siltstone underlain by burning coal veins. The degree to which the original strata are altered depends on the intensity of the heat,

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<sup>2</sup> Terms for material altered by burning coal veins include scoria, porcelanite, clinker, and slag. In coal geology, the term porcelanite refers to fused shale and clay; however in sedimentary petrology the term refers to a marine silicious rock (Encyclopedia of Sedimentology, 1978). Scoria, the local term, actually implies a basalt origin. Apparently an unambiguous term has not been defined yet. In this report the coal geologist's definition will be used for porcelanite. "Baked sandstone" will be used to differentiate it from baked rocks of shale or clay origin.



rapidity of cooling, and the composition of the stratum (Rogers 1918). Shale is more susceptible to a complete textural and compositional change than sandstone (Rogers 1918). Rogers (1918) recognized four types of altered materials. The most predominant type is baked shale (porcelanite) or baked sandstone (harder than the original rock with a reddish hue, but no change in composition or structure); smaller amounts of vitrified shale (banded green, red, and black flow lines and vesicular structure), glassy slag, and recrystallized slag also occur. Porcelanite forms beds up to 100 feet thick and up to a mile wide (Dobbin 1930). The horizontal orientation of the flattened fragments and their staggered arrangement may provide microtraps for water, but porcelanite's influence on soil moisture regimes has not been studied.

## SOILS

Three orders of soils dominate the landscape near Colstrip: Aridisols, Entisols, and Mollisols. Mollisols form under grassland vegetation on toe slopes or gently rolling topography. Entisols and Aridisols are found on strongly sloping to very steep slopes on dissected uplands. Ponderosa pine and Rocky Mountain juniper are largely associated with Entisols and to a lesser extent Aridisols in the area. Table 1 summarizes characteristics of the major soil series supporting coniferous species near Colstrip. In general, the upland soils are shallow, skeletal, calcareous, weakly developed, erosive, and rocky.

Table 1. Orders, subgroups and series descriptions of soils frequently associated with Ponderosa pine and Rocky Mountain juniper near Colstrip.  
 NOTE: Series names and descriptions are taken from the proposed Rosebud County Soil Survey and are subject to final approval  
 (Lou Daniels, Soil Conservation Service, Forsyth, MT. - personal communication, July, 1980).

ORDER	GENERAL DESCRIPTION	SUBGROUP	GENERAL DESCRIPTION	FAMILY	SERIES	DESCRIPTION
Entisol	- very little development of horizons (no B, shallow A)	Ustic Torriorthent	- develops on recent erosional surfaces - frigid temperature regime (MAT < 47°F)  - aridic-ustic moisture regime (most of the soil moisture control section is dry throughout a large proportion of the growing season)	fragmental, mixed, frigid	Kirby (tentative)	- channery or sandy loam formed from porcelanite or sandstone - well-drained, slow runoff, rapid permeability - pH ± 8.2 A1 -- 0-4" channery loam; 40% porcelanite; weak effervescence Clca -- 4-12" 80% porcelanite lime coats on coarse fragments C2 -- 12-60" 5% fines
				loamy, mixed, frigid	Cabbart	- weathers from siltstone - platy sedimentary beds at 7-20" - well-drained, medium to rapid runoff, moderate permeability - pH ± 8.4 - A1 -- 1-4" strongly effervescent loam - Clca -- strongly effervescent loam - C2ca - C4 -- 16-60" platy siltstone and fine grained sandstone
Aridisol	- very little moisture for plant growth - more developed horizonation than Entisols	Borollic Camborthid	- cambic B horizon - forms on late-Pleistocene or younger surfaces - mean annual soil temperature 8°C (46.4°F)	loamy-skeletal, mixed, frigid	Birney	- deep, well-drained soils that develop from sandstone, shale or porcelanite - medium runoff, moderate permeability - pH ± 8 A1 -- 0-5" channery loam; 15% shale and sandstone fragments B2 -- 5-11" 20% shale and sandstone fragments; moderate effervescence; channery loam Clca - C2 -- 29-60" very channery sandy loam; 65% hard shale and sandstone fragments.

## CLIMATE

Sunday, August 14, 1857 (13 miles north of present day Colstrip):

The day has been exceedingly warm, the thermometer standing at 108° Fahr., the difference between the wet and dry bulbs being 40°. A high northwest wind this afternoon gives promise of more agreeable weather. Last night, however, I was cold under two blankets, and the change is most remarkable between the day and night temperatures. (Raynolds 1867)

General Raynold's journal entry provides a vivid description of the semi-arid, continental climate of the Colstrip area; large diurnal and seasonable temperature differences, low relative humidity, and light precipitation.

The mean annual precipitation is 40.1 cm (15.8 inches) with extremes ranging from 13.7 cm (5.4 in., 1979) to 62.7 cm (24.7 in., 1944) (NOAA 1979). Figure 1 shows the variation in annual precipitation from 1878 to 1980. Approximately 75% of the precipitation falls within the growing season (May - September). June is the wettest month, which is typical for the prairie zone east of the Rocky Mountains (Walter *et al.* 1975).

Mean monthly temperatures range from -6.1°C (21.0°F) in January to 21.9°C (71.5°F) in July with a yearly mean of 7.7°C (45.9°F) (NOAA 1979). Extremes have been recorded from -10°C (-50°F) to 44°C (111°F). The average freeze-free season is about 120 days.

Solar radiation varies with latitude, declination of the sun (time of year and time of day), aspect, and percent slope. Figure 2 shows estimated total annual radiation for slope-aspect combinations for the

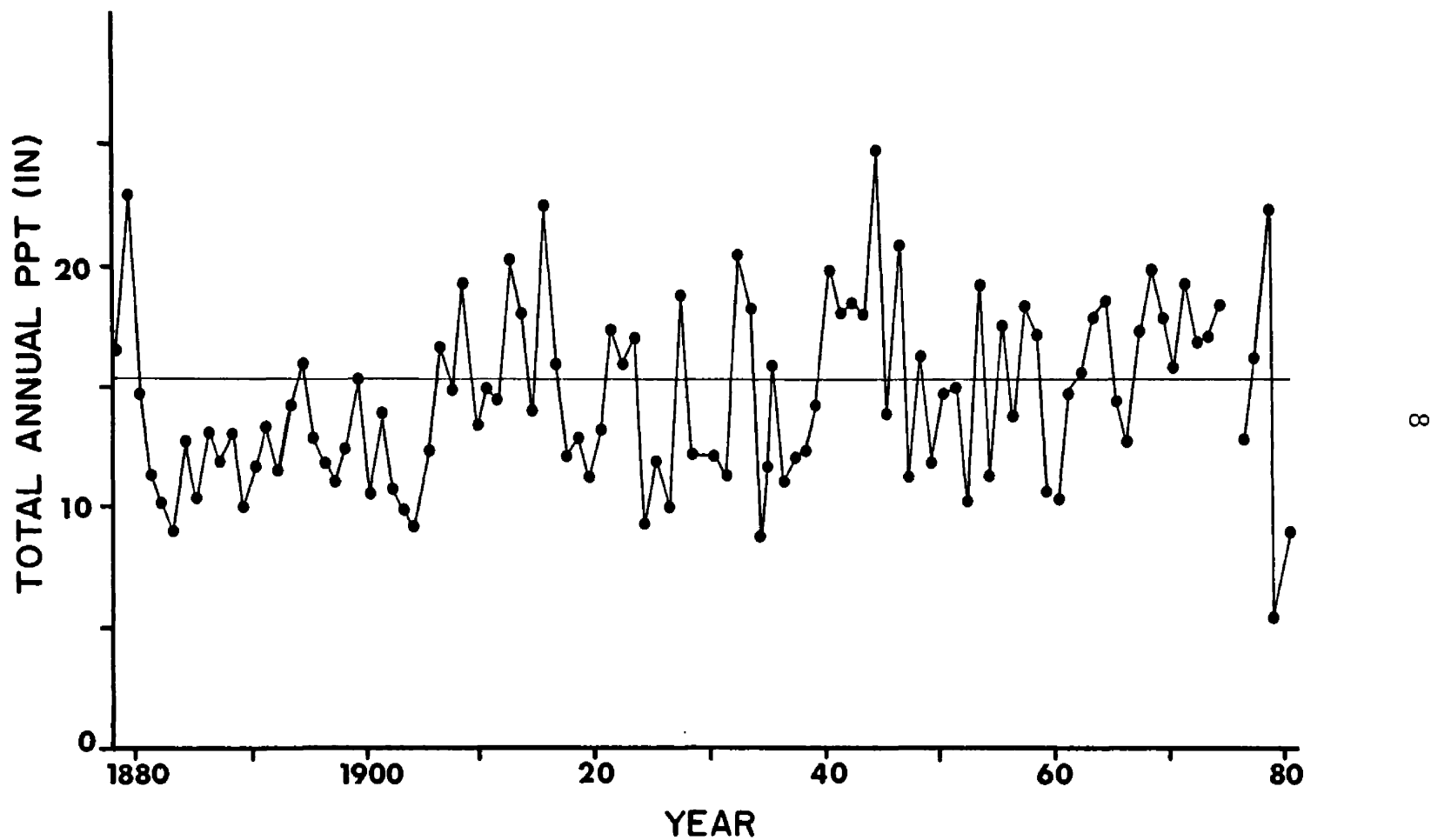


Figure 1. Annual precipitation (inches) for 102 years near Colstrip, MT. Horizontal line shows mean precipitation at Colstrip based on 52 years (1975 missing). Data previous to 1928 are from Miles City, MT.

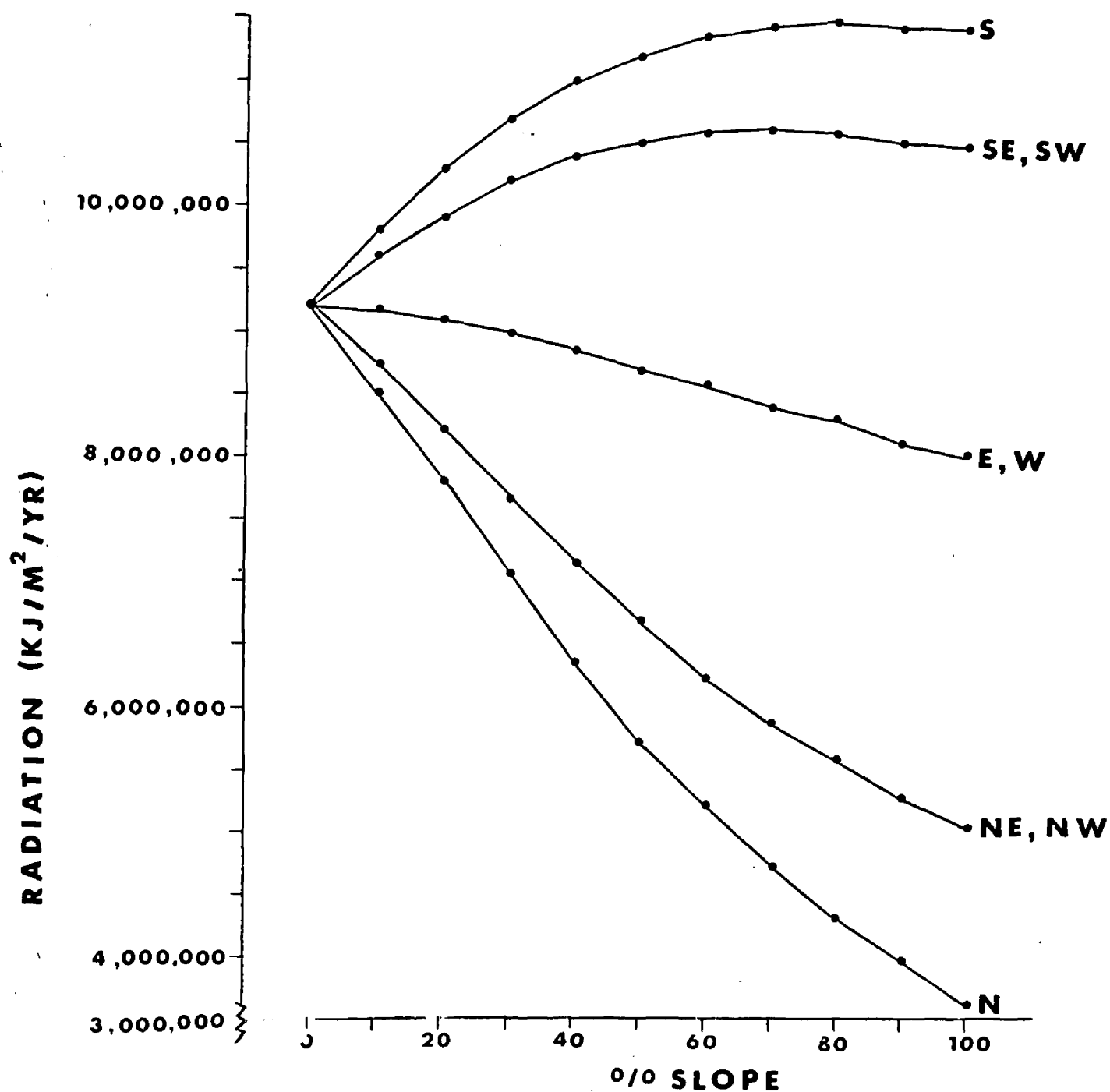


Figure 2. Total annual solar radiation (direct plus diffuse) in kilojoules/m<sup>2</sup>/year for various slope-exposure combinations at 45°53'N. latitude. Estimates assume clear skies and vegetation-free surfaces.

latitude of Colstrip (45°53'N). The differences in radiation loads on north slopes versus south slopes rapidly increase as steepness increases.

Potential evapotranspiration greatly exceeds precipitation near Colstrip. Figure 3 shows estimated monthly potential evapotranspiration in relation to mean monthly precipitation and temperature. Annual potential evapotranspiration estimated by the Priestly-Taylor equation (Campbell 1977) is 913 mm (35.9 in.). Actual evapotranspiration is far less due to the lack of precipitation and soil moisture late in the growing season.

Colstrip lies in the Alberta storm belt (Coupland 1958) which transports continental air from the eastern slopes of the Rocky Mountains. The average wind speed is 17.3 km (10.8 miles) per hour and is predominantly from the west or northwest (Montana Department of State Lands 1976). Summer thunderstorms are sometimes accompanied by hail.

### VEGETATION

Colstrip is located in the Southeastern Montana Forest Region (Arno 1979) which supports predominantly cool-season mixed prairie grasses, pine savanna and pine forests.<sup>3</sup> Coniferous species include

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<sup>3</sup> Savanna is defined as < 25% tree cover; forest is defined as ≥ 25% tree cover (Penfound 1967).

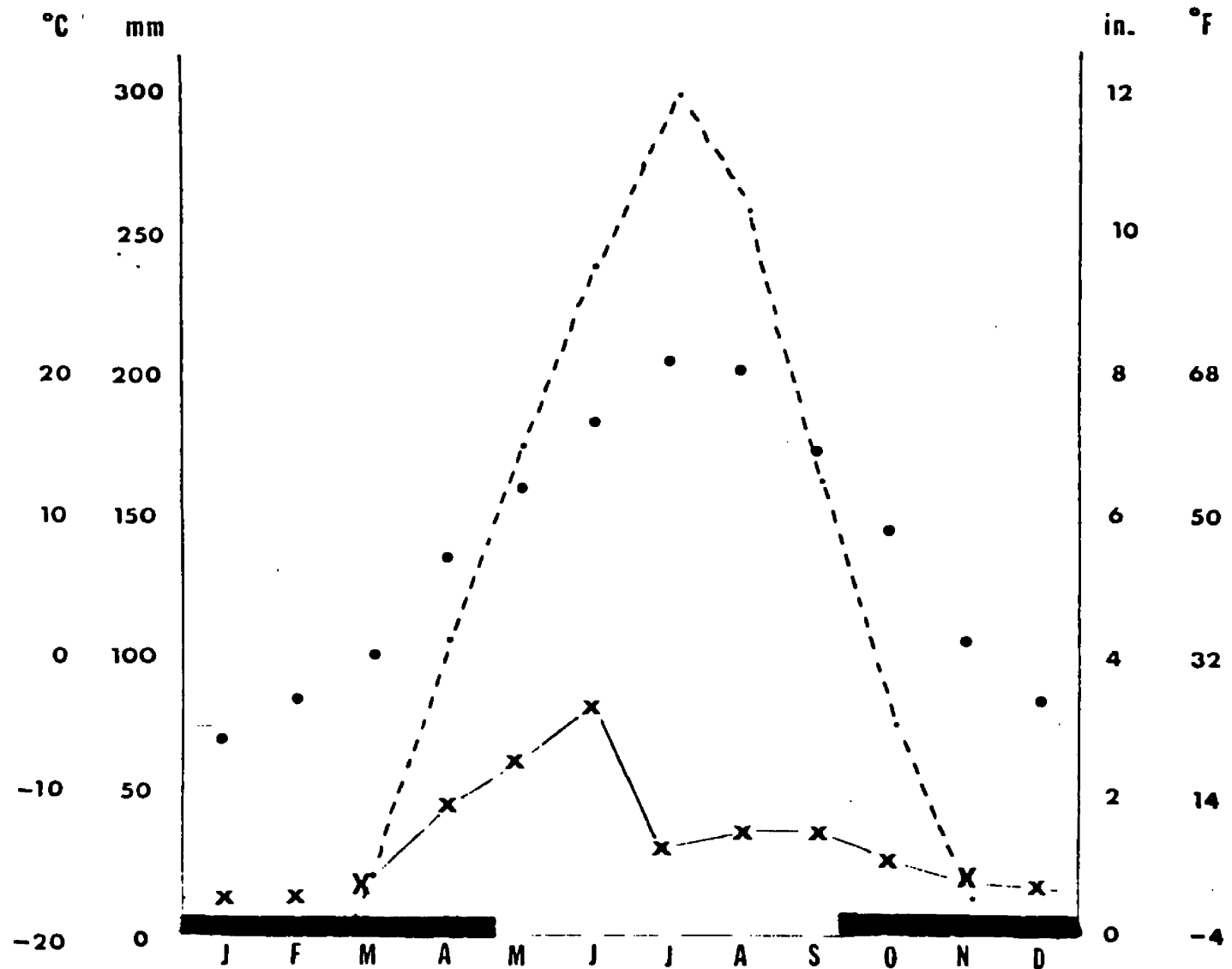
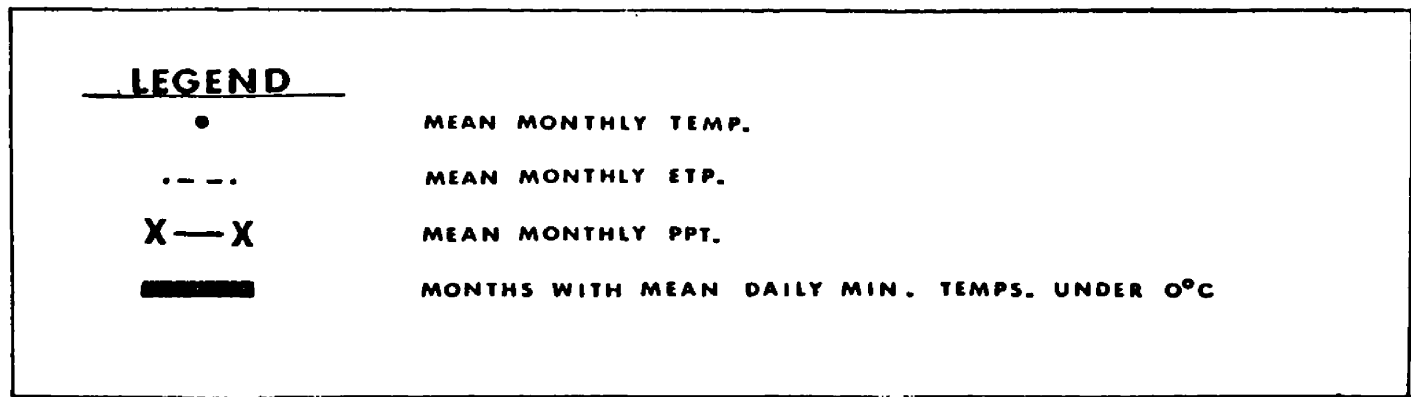


Figure 3. Mean monthly temperature (49 years), precipitation (51 years), and estimated potential evapotranspiration (Priestly-Taylor method) at Colstrip, Montana. Solid bars show months with mean daily minimum temperatures under 0°C. (Note: scale in English units is approximate.)

*Pinus ponderosa* var. *scopulorum*, *Juniperus scopulorum*, and very scattered *Juniperus horizontalis* (Creeping juniper). Coniferous species are largely associated with sideslopes of ridges, knolls and buttes but also occur on gently rolling, sandy uplands and in draws. The topographically controlled juniper and pine distribution patterns are frequently cited in the western Great Plains (Wells 1970, Potter and Green 1964, Erdman *et al.* 1969, Juhnsen 1962).

Several investigators have classified vegetation in southeastern Montana (Brown 1965, Coenenberg and DePuit 1979, S. Cooper [work in progress, Forestry Sciences Lab, Missoula, Mt.], Payne 1973, Pfister *et al.* 1977, Ross and Hunter 1976, Taylor and Holst 1976). Payne (1973) considered the Colstrip area as ponderosa pine savanna, whereas Ross and Hunter (1976) distinguished between a forest-grassland complex (Type 25) and a silty-clayey eastern sedimentary plains complex (Type 16). Taylor and Holst (1976) described dry and moist slope ponderosa pine communities in the Ashland and Fort Howes Ranger Districts of the Custer National Forest south of Colstrip. Brown (1965), working in the same area, distinguished between ponderosa pine - Rocky Mountain juniper and Rocky Mountain juniper - bluebunch wheatgrass (*Agropyron spicatum*) communities.

Pfister *et al.* (1977) identified three ponderosa pine habitat types dominating southeastern Montana: ponderosa pine - bluestem (*Andropogon gerardii* or *Schizachyrium scoparium*), ponderosa pine - bluebunch wheatgrass, and ponderosa pine - chokecherry (*Prunus virginiana*). Pfister's classification is currently being modified for



southeastern Montana (Steve Cooper, personal communication, 1980).

Coenenberg and DePuit (1979) classified vegetation types on the Crow Indian Reservation (southwest of Colstrip) in conjunction with a wildlife population study. They described seven conifer-dominated subtypes including ponderosa pine forests, ponderosa pine - juniper forests, ponderosa pine - grasslands, ponderosa pine - deciduous shrubs, ponderosa pine - big sagebrush (*Artemisia tridentata*), ponderosa pine - silver sagebrush (*Artemisia cana*) and Rocky Mountain juniper.

Existing vegetation classifications have limited applicability to the study area due to geographical (hence, floristic and climatic) differences or broad scale resolution. Stands near Colstrip generally resemble the ponderosa pine - bluebunch wheatgrass and rarely, the ponderosa pine - bluestem (*Schizachyrium scoparium* or *Andropogon gerardii*) habitat types described by Pfister *et al.* (1977) except that the forest ( $\geq 25\%$  tree cover) condition is often not met. Coenenberg and DePuit's (1979) classification is limited by qualitative delineations, but because it offers the best combination of floristic affinity and fine resolution, it was used to classify stands near Colstrip.

Shrubs and graminoids most frequently associated with ponderosa pine and Rocky Mountain juniper near Colstrip include *Artemisia tridentata*, *A. cana*, *Rhus trilobata* (skunkbush sumac), *Xanthocephalum sarothrae* (broom snakeweed), *Symphoricarpos occidentalis* (western snowberry), *Rosa woodsii* (woods rose), *Yucca glauca* (yucca), *Agropyron spicatum*, *A. smithii* (western wheatgrass), *Schizachyrium scoparium*,

*Bouteloua gracilis* (blue grama), *B. curtipendula* (side oats grama), *Aristida longiseta* (red threeawn), *Koeleria cristata* (prairie junegrass), *Stipa comata* (needle-and-thread), and *Carex filifolia* (threadleaf sedge).

On north slopes, ponderosa pine and Rocky Mountain juniper frequently intergrade into a *Rhus trilobata* - *Symphoricarpos occidentalis* - *Agropyron spicatum* complex. South slopes, which support sparser tree cover often intergrade into an *Agropyron spicatum* - *Rhus trilobata* - *Yucca glauca* complex.

#### LAND USE

Historically, the dominant land use near Colstrip has been grazing. Archaeological surveys of the area indicate that bison were an important food source for indigenous people, occupying the area around 12,000 years ago until around 6000 years ago and from about 5000 years ago until the late 1800s. During the warm, dry Altithermal period (ca. 6000 B.P. to 5000 B.P.) bison possibly migrated to moister areas to graze (Fredlund 1973). General W. Reynolds who led an expedition of surveyors and geologists through the Yellowstone drainage in 1857 observed bison "whose numbers defy computation, but must be estimated by hundreds of thousands" grazing in the Yellowstone Valley north of Colstrip (Reynolds 1867). He also observed antelope, elk, wolves, and grizzly bears in the vicinity.

White settlement in the area began around 1842 when Fort Alexander was built near the confluence of Armell's Creek and the Yellowstone

River. The demise of the bison by 1883 coincided with the establishment of the first large cattle company on Armell's Creek. Migratory cattlemen had occupied the area since the 1850s, but until Native Americans were contained on reservations, the area largely supported transients. White settlement also brought about a shift in the patterns of land use inasmuch as Native Americans had occupied pine/sandstone zones and whites settled in alluvial bottomlands (Fredlund and Fredlund 1974).

Homesteaders supplanted open-range cattlemen by the 1920s. Attempts to farm the marginal cropland suffered severe setbacks in the droughts of the late 1910s and in the 1930s, whereupon many acres were returned to rangeland (historical land use summary based on Stephan, 1974). However, some small grain production has continued until the present.

Colstrip was established in 1924 by the Northern Pacific Railroad to supply sub-bituminous coal for the railroad's steam locomotives. Western Energy, a subsidiary of Montana Power Company, purchased the coal operations in 1968. Since 1968 approximately 3200 acres have been mined. Mining in the area is expected to continue for another 30 to 40 years at a rate of roughly 300 acres per year (Joe Coenenberg, Western Energy, personal communication). Following bond release, most acreages will be returned to rangeland for livestock grazing and wildlife use.

Timber use in the area is minimal. Ponderosa pine was used previously for settlers' homesites and firewood. Rocky Mountain juniper

is occasionally cut for fence posts.

### METHODS

Twelve stands were sampled within 5 miles of Colstrip (Figure 4). Three stands (Stands 1, 4, and 5) were selected because data on tree rooting characteristics were available (Stout 1980); the remaining stands were chosen randomly from aerial photographs. Natural breaks in topography or physiognomy were used to delimit stands, however stand boundaries were arbitrary. Only upland stands were sampled; draws were excluded. Stand descriptions are included in Appendix A.

Within each stand, a stratified, partially systematic, partially random sampling design was used. Two transects were systematically laid out parallel to ridgelines on aerial photographs of sample stands. The ridgelines generally run in an east-west (ESE-WNW) direction, therefore the transects were on southern or northern exposures. Tree plots and seedling sub-plots were located along transects in the following manner. The first tree plot was located randomly; subsequent tree plots were located systematically at pre-established distances to cover the length of the transect. Two seedling sub-plots were located at random distances (within 30 m.) and random bearings from each tree plot.

Plot size was determined by modifying species/area curve techniques (Mueller-Dombois and Ellenberg 1974) to an average density curve. Trees and seedlings were recorded in a series of concentric plots with the same center point and increasing radius until the num-

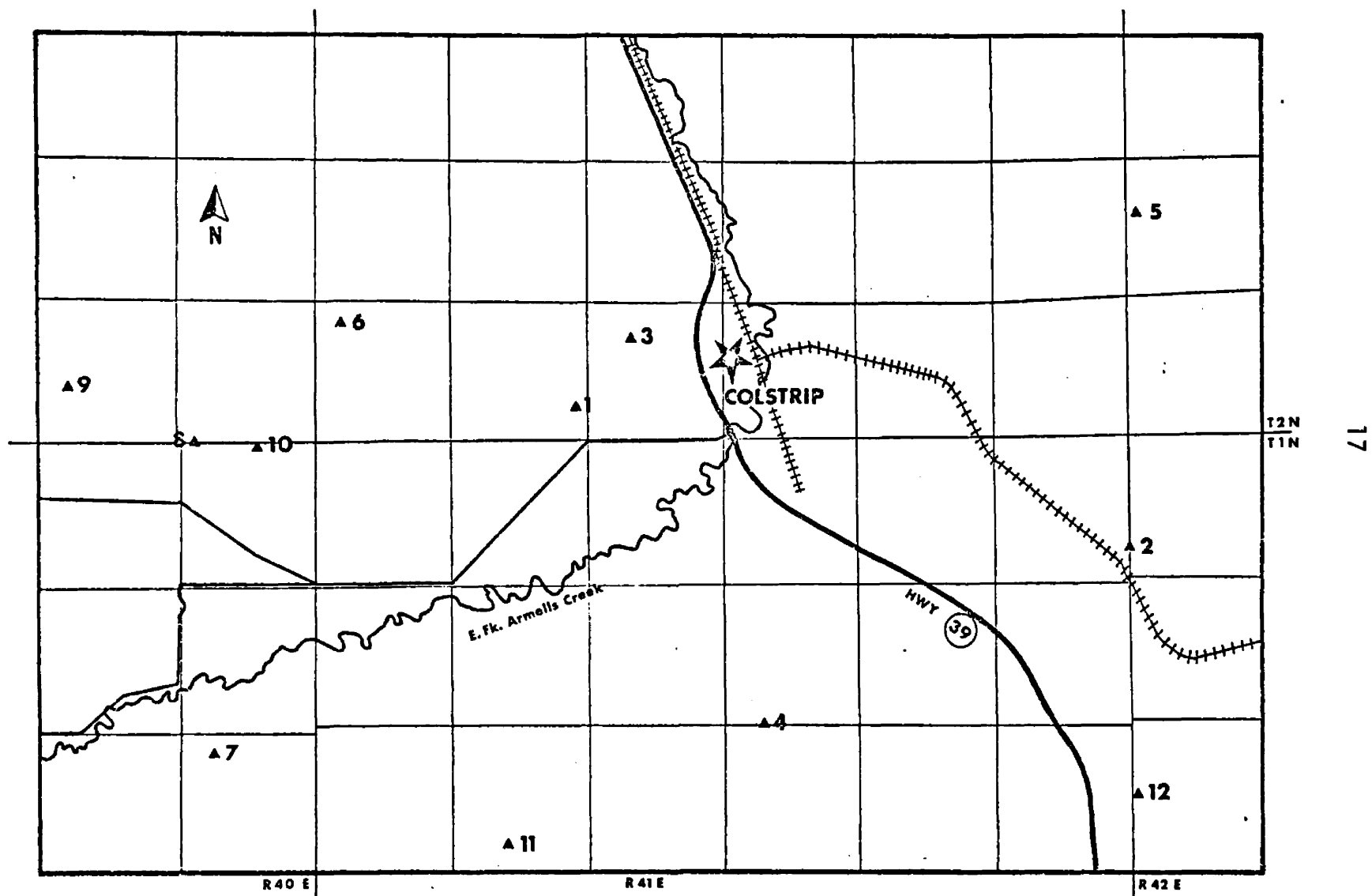


Figure 4. Location of sample stands



ber of stems per unit area stabilized. The process was repeated for several center points in savanna and forested areas. Results indicated that the following ranges in plot sizes would be optimum for the study:

Savanna (usually south exposure): < 25% tree cover

Tree Plots: 700-1500 m<sup>2</sup>

Seedling Sub-plots: 300-500 m<sup>2</sup>

Woodlands (usually north exposure):  $\geq$  25% tree cover

Tree Plots: 50-500 m<sup>2</sup>

Seedling Sub-plots: 25-200 m<sup>2</sup>

Sampling intensity was determined by a percentage limit (Mueller-Dombois and Ellenberg 1974) such that at least seven percent of the stand area was sampled. In most cases, four tree plots (eight seedling sub-plots) were located along each transect; however, in two small stands only two tree plots (four seedling sub-plots) were sampled.

The following observations were recorded for each tree plot: aspect (degrees), percent slope, configuration (convex, concave, undulating, flat), parent material, percent rock exposed at surface (closest 10%, polygon method rather than foliar cover), slope position (ridgetop, upper, mid, or toe slope), calcareousness (positive or negative effervescence with dilute hydrochloric acid), herbaceous and shrubby species, percent tree cover; diameter (closest inch at breast height), height (closest foot), species, severity and type of damage (porcupine, insect, fungal, mechanical damage) of all trees. Mature pine trees were aged by basal increment cores. Three years

were consistently added to each ring count to allow for the 2-6 in. distance from the base of the tree to the extracted core. Estimated total age was assumed to be within 5 years of the actual age. Additional cores or wedges were taken from trees which had fire scars. Observations were made as to grazing use, cone production, logging evidence, and amount of rodent disturbance.

The following observations were recorded on seedling sub-plots: percent slope, aspect, configuration, and slope position (if different from tree plot); seedling species, height (closest tenth of a foot), vigor ("very feeble", "feeble", "normal", "exceptionally vigorous" after Mueller-Dombois and Ellenberg 1974), percent cover of rocks and non-tree species (within a 1-ft. radius of each seedling), percent bare mineral soil (within a 3-in. radius of each seedling), mammal, insect, and fungal damage (type and severity), whether seedling was cached or not, and intervals of shade for each seedling. All pine seedlings were aged by counting terminal bud scars. Juniper seedlings were not aged because accurate estimates can only be obtained by destructive sampling.

Shade intervals were determined by taking bearings to objects (the horizon, trees, or rocks) which subtended solar angles to each seedling. Solar angles (vertical angle to the sun) were determined from sunrise to sunset for latitude  $45^{\circ}53'$  on summer solstice. Shade was assumed to reduce direct sunlight by 90% throughout the interval of shade. If the object providing shade was an open-crowned pine tree the seedling would actually receive more than 10% direct sun-

light. On the other hand, when rocks provided shade, the seedling would receive less than 10% direct sunlight.

A computer program was utilized to estimate the potential radiation each seedling would receive without shade (Buffo *et al.* 1972). Potential radiation estimates were based on the slope and aspect of each seedling plot and the latitude of Colstrip. Estimates of the actual radiation each seedling received were computed by modifying the program based on the duration and the time of day seedlings were shaded.

Density (number of stems/hectare) and basal area were determined for each species, age class (ponderosa pine), or diameter class (Rocky Mountain juniper), and exposure (north or south) for each stand. Analysis of variance and Duncan's multiple range tests were used to compare density, basal area, and height/age ratios on north and south facing exposures within and between stands.

Multiple regression techniques were used to analyze relationships between density, basal area, and height/age ratios as dependent variables against various combinations and transformations of potential solar radiation, actual solar radiation, rockiness, vegetative cover, bare mineral soil, slope, and age of stand (independent variables). In addition, mean decadal precipitation was regressed over decadal tree density and yearly precipitation from 1970 to 1979 was regressed over yearly seedling density. Due to time constraints some factors which influence regeneration in the area were not considered. Soil moisture data were not available; the influence of wind, snow accumulation and snow melt patterns, cold hardiness and winter mortality, erosion, mycorrhizae, and possible allelopathic interactions were not considered.



## RESULTS AND DISCUSSION

### SEEDLINGS

Water availability and high surface temperatures are probably the primary factors limiting the regeneration and survival of conifers near Colstrip. Nutrient, light, and biotic conditions may occasionally prevent germination or cause early mortality, but are secondary to the lack of moisture or high surface temperatures in controlling establishment.

Most of the variables that were measured in the seedling plots were either directly or indirectly influencing moisture availability in seedling microsites. Each of these variables is discussed in the following sections.

### SHADE

Partial shade was the most ubiquitous factor associated with pine and juniper seedlings near Colstrip. Eighty-nine percent of the pine seedlings and all of the juniper seedlings grew under partial shade provided by established trees, shrubs or rocks. Table 2 compares shade conditions between pine and juniper seedlings. Although shade was important to both species, pines were generally growing under more intense radiation loads than junipers (Table 2).

In discussing the importance of shade to seedlings it is important to consider basic physiological requirements of the species. Ponderosa pine and juniper seed germination is limited by moisture and temperature rather than light (Harrington 1977, Johnsen 1962, Kozłowski

Table 2. Shade conditions for ponderosa pine (PIPO) and Rocky Mountain juniper (JUSC) seedlings ( $\leq 1$  meter tall) near Colstrip.

	PIPO	JUSC
Number of Seedlings		
Partially Shaded (%)	89	100
Unshaded (%)	11	0
$\bar{X}$ Percent of Full Sunlight*	68	60
Actual Radiation <sup>†</sup> (kJ/m <sup>2</sup> /DAY)		
Mean	26,176	21,905
Standard Error	348	700
Range	3039-36,429	3068- 32,811
$\bar{X}$ Reduction of Potential Sunlight	9656	14,698

\* Data include diffuse and direct solar radiation on summer solstice (June 21).

† Actual radiation is the estimated amount of diffuse and direct radiation each seedling received throughout the day (June 21). Shade was assumed to allow 10% of direct solar radiation through to the seedling via sunflecks. No reductions were made for cloudy conditions.

1971a). Optimum temperature for germination of pine is 21°C (70°F, Tinus and McDonald 1979) and 10°C (50°F, Meines 1965) for juniper. Meines (1965) reported that juniper germination may cease at temperatures higher than 15.5°C (60°F). Surface temperatures of 55°C (131°F) have been observed near Colstrip (Rhonda McCann, 1981, personal communication) and are probably common during summer months. Shade can reduce soil surface temperatures by 17°F (Maguire 1955). Therefore, the presence of shade may be very important for germination of pine and juniper seeds by reducing surface temperatures.

Physiological light requirements of ponderosa pine depend on temperature and moisture conditions. The light compensation point (when photosynthesis equals respiration) varies directly with temperature and inversely with moisture stress (Hadley 1969, Helms 1972). Ponderosa pine in southwestern North Dakota has light compensation points ranging from 135 (at 9°C) to 520 (at 24°C) foot-candles (Hadley 1969) ( $\sim 1223$  to  $4714 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ).<sup>4</sup> Light compensation points may be 3.5 times greater when moisture is limited (Atzet and Waring 1970) (e.g.  $\sim 4280$ – $16,499 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). Light saturation points (when additional light does not increase photosynthesis) range from 3000 to 8000 foot-candles (Hadley 1969 ( $\sim 27,199$  to  $72,529 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). The latter figure is greater than what occurs naturally, thus when moisture and temperature are not limiting, ponderosa pine could theoretically utilize more light than it naturally receives.

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<sup>4</sup> Conversions from foot-candles to  $\text{kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  are approximate.

When seedlings germinate under very heavy shade and high moisture stress eventual mortality would be expected. However, most seedlings were establishing above the range of reported light compensation points (Hadley 1969, Atzet and Waring 1970) (Table 2) and often above the reported minimum light saturation point. These results suggest that neither minimum nor maximum solar radiation directly limits the early establishment of conifers near Colstrip. However, the indirect effects of intense radiation (higher temperatures and greater evapotranspiration) can severely limit establishment.

Young seedlings are susceptible to two other forms of possible injury or death which shade helps to prevent: heat stress and moisture stress. The cambium of pine seedlings is lethally disrupted by soil surface temperatures greater than 54°C (129°F, Cleary *et al.* 1980). Buchanan *et al.* (1977) reported lower moisture stress (an average increase of 2 bars) in ponderosa pine seedlings that were shaded from afternoon sunlight. Lower moisture stress is attributed to reduced transpiration (Buchanan *et al.* 1977, Lopushinsky 1969). Other investigators who have noted the importance of partial shade in ponderosa pine establishment include Schubert (1974), Zavitkovski (1970), and Stoeckler (1970).

Interactions between light, moisture and temperature requirements of Rocky Mountain juniper have not been adequately determined. Tinus and McDonald (1979) report broader optimum temperature ranges (21°-28°C) for growth of greenhouse *J. scopulorum* seedlings compared to pine seedlings. Wambolt (1973) reported higher average water stress

of Rocky Mountain juniper in comparison to ponderosa pine in the Big Horn Mountains. Running and McCann (1980) also found greater water stress (more negative water potential) on junipers compared to pines near Colstrip. The results of this study showing significantly lower radiation loads on juniper seedlings compared to pine seedlings (Table 2) were anomolous. Given that junipers tolerate greater moisture stress and generally are observed on more xeric sites than ponderosa pine, I expected to find juniper seedlings growing under greater radiation loads than pines. The results may be due in part to low temperature germination requirements of juniper. Studies of *Juniperus monosperma* (Johnsen 1962) and *J. occidentalis* (Burkhardt and Tisdale 1976) also emphasize the importance of shade to juniper establishment.

Two other trends were evident from analyzing radiation loads on seedlings. The amount of shade (potential minus actual direct and sky diffuse solar radiation) seedlings received was positively correlated with the potential radiation of the site ( $p = 0.01$  for pines;  $p = 0.05$  for junipers). In other words, seedlings surviving on south-facing slopes were more heavily shaded by rocks, shrubs and established trees than seedlings on north-facing slopes. The average reduction of solar radiation on south-facing slopes was 50%; on north-facing slopes 43%. The actual radiation seedling received on north- versus south-facing slopes did not significantly differ.

The other trend that was observed is that as seedlings age the amount of light that "benefits" them gradually increases. Correlation coefficients between actual radiation and height in each age class

suggest that optimum levels of shading vary from about  $21,000 \text{ kJ} \cdot \text{m}^2 \cdot \text{day}^{-1}$  for first-year germinants,  $27,000 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  for one to three year old seedlings, and  $30,000 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  for seedlings from four to ten years old. The values correspond to roughly 50%, 70%, and 75% full sunlight (on level ground), respectively. Figure 5 shows potential radiation on summer solstice for slope-aspect combinations near Colstrip. The amount of shade should be adjusted for the slope and aspect of the planting site.

#### SURFACE ROCKINESS

Like shade, the function of rocks in improving seedling microsites, may be due to improved moisture regimes. Table 3 shows that both pine and juniper seedlings were associated with equal mean surface rocks (8%) although the variance for juniper was greater. Subsurface rockiness was not measured, but observations showed that rockiness quickly increased with increasing soil depth in most plots. Mean percent surface rockiness associated with both species was low. However, the surface rock conditions were underestimated because rocks that were covered with litter or vegetation were not recorded in rock percentages. Percent surface rockiness did not significantly correlate with vigor of pines or juniper seedlings or height/age ratios of pine seedlings.

The effectiveness of rocks in providing extra moisture for seedlings depends on the type and depth of rock, the degree of weathering, and the characteristics of the fractures. Seedlings establishing in massive sandstone are limited to freeze-thaw cracks (see Figure 6A) or shallow sand-filled pockets. Procelanite provides many more establish-

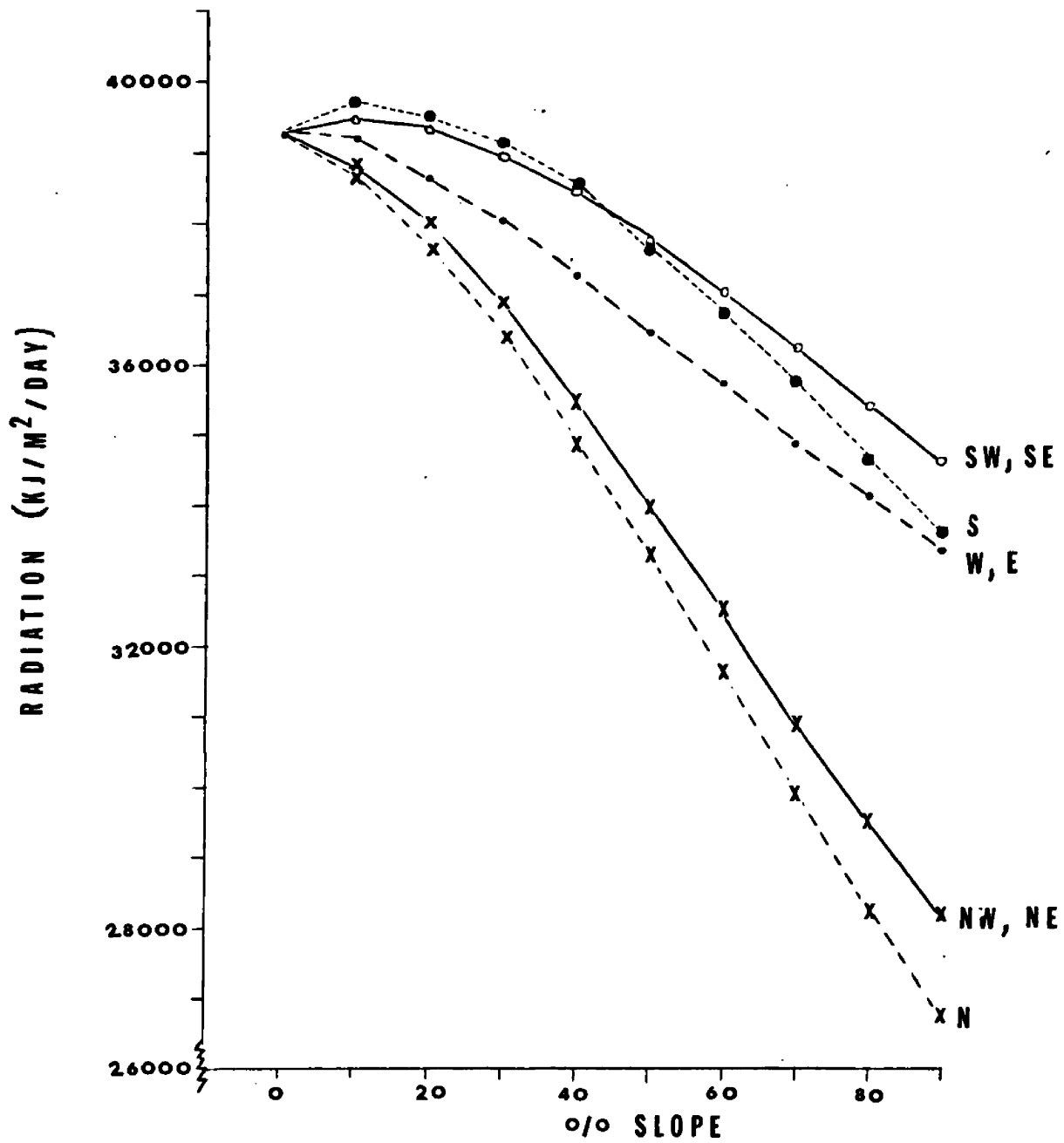


Figure 5. Potential solar radiation (direct and sky diffuse) in  $\text{kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  by percent slope and aspect on summer solstice (June 21) at latitude  $45.3^\circ \text{ N}$ .

Table 3. Means, standard errors, and ranges of microsite variables associated with ponderosa pine (PIPO) and Rocky Mountain juniper (JUSC) seedlings near Colstrip.

	PIPO	JUSC
Numb	621	106
Surface Rockiness* (%)		
Mean	8.2	7.7
Range	0-100	0-90
Standard error	0.6	1.2
Vegetative Cover (%) <sup>†</sup>		
Mean	27.0	14.3
Range	0-100	0-90
Standard error	0.8	1.8
Bare Mineral Soil <sup>‡</sup> (%)		
Mean	11.2	13.9
Range	0-100	0-90
Standard error	0.9	2.5

\* Rocks are any coarse fragments with one dimension  $\geq 1$ ". Percent surface rockiness and percent vegetation (graminoids, forbs and shrubs) were estimated to the closest 10% in a one foot radius around seedlings.

† Significant difference between species at  $p = 0.05$

‡ Bare mineral soil was estimated to the closest 10% in a three inch radius around seedlings.



ment sites due to its highly fractured horizontal fragments. Metamorphosed vesicular shale provides limited establishment sites (see Figure 6B).

Rocks can provide extra moisture for seedling establishment in two ways: by concentrating moisture and by preventing evaporative losses. Branson *et al.* (1964) reported less runoff, greater infiltration, greater water availability (lower tension), and more mesic vegetation on stony soils as compared to finer Pierre Shale soils near Golden, Colorado. Erdmann *et al.* (1969) and Potter and Green (1964) suggested that the association of mesic species with rocky substrates in semi-arid areas was due to temporary water reservoirs rock fissures provide. Stark (1980) discussed the importance of rocks in acting as a barrier to evaporative losses by the distillation-condensation theory. Her work in Death Valley (Stark 1973) showed that water vapor moved upward through the soil column during the day and condensed on the undersides of rocks when temperatures dropped at night. Johnsen (1962) recorded 2-2.5 times as much available moisture in shallow soils overlying rock outcrops in Arizona and reported that *Juniperus monosperma* was largely limited to rock outcrops. The lack of rocks in topsoil on mined land near Colstrip may essentially create a more xeric soil environment for seedlings.

Pine seedlings were observed in natural porcelanite mulches in several locations near Colstrip, even on severe south-facing exposures. In most cases, the mulch was less than one inch thick and was composed of small (1 in. - 2 in.) porcelanite fragments. The occurrence of



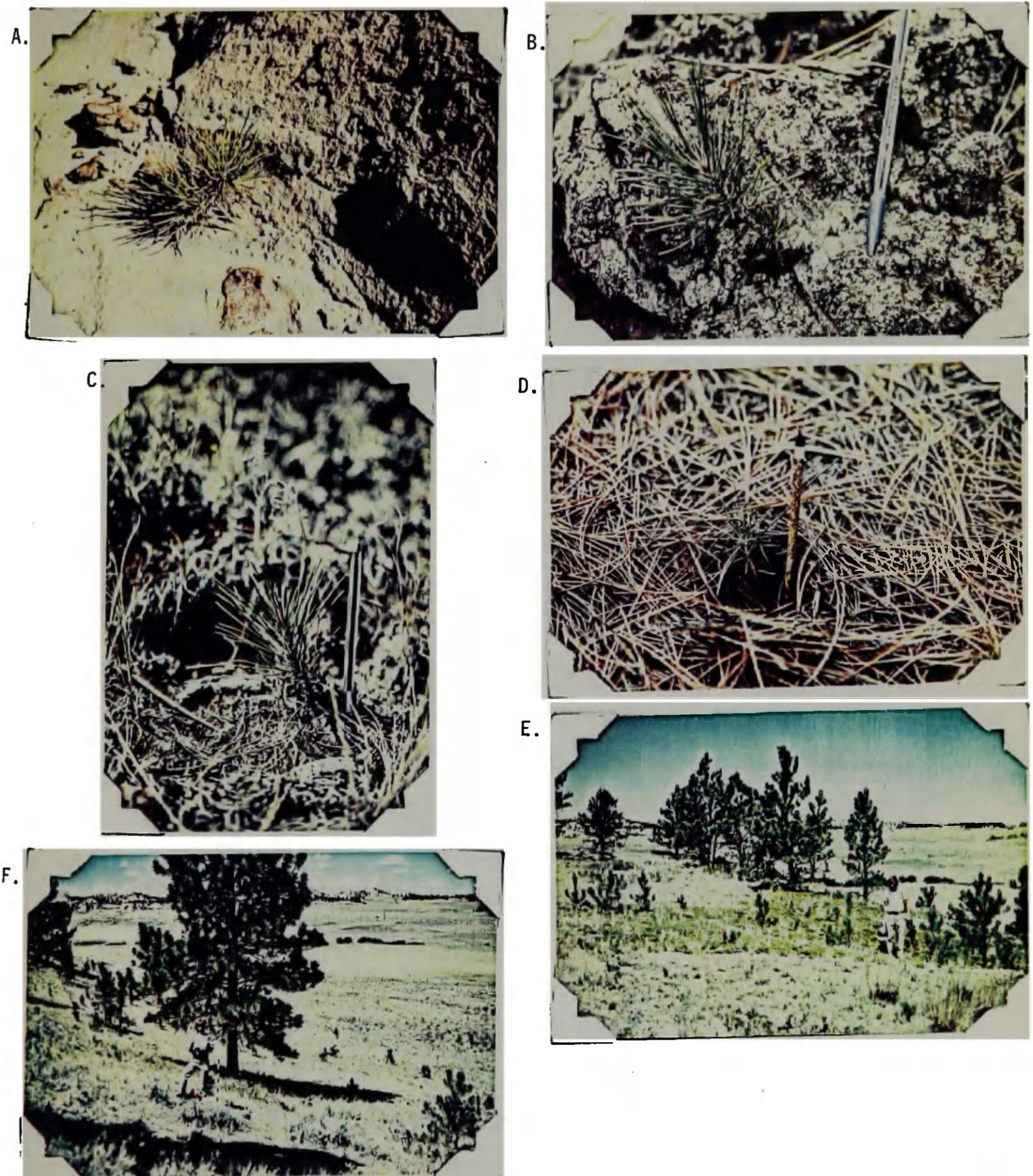


Figure 6. Pine seedlings establishing in A) fissures of massive sandstone, B) vesicular shale, C) "microtrough", D) 2 1/2" litter, E) a *Juniperus horizontalis* patch, and F) a downslope grass-dominated community.



seedlings in these areas emphasizes the possible effectiveness of the condensation-distillation vapor barrier in conserving moisture.

Rock or gravel mulches have been used successfully in Arizona and the northern Great Plains. Heidmann *et al.* (1977) improved ponderosa pine survival from 68% to 81% using a rock mulch near Flagstaff, Arizona. Stoeckeler (1970) used a 2 in. gravel layer to establish ornamental conifers in the northern Great Plains. The technique offers another advantage in that it helps prevent very dense coverages of herbaceous vegetation from developing around seedlings (Stoeckeler 1970).

#### INTERSPECIFIC COMPETITION

Pine seedlings were associated with significantly greater coverages of competing vegetation than juniper seedlings (27% and 14%, respectively; see Table 3). Height/age ratios of pine were positively correlated ( $p = 0.01$ ) with the amount of vegetation within a one foot radius of the seedlings. As expected, the average amount of competing vegetation increased slightly with increased seedling age; first year germinants were associated with an average of 22% cover and ten year old seedlings were associated with an average of 33% cover within a one-foot radius of the seedlings.

To a limited extent, some species appeared to function as a "nurse crop" for pine seedlings. Pine seedlings were occasionally found growing within clumps of warm season grasses such as *Schizachyrium scoparium*, within patches of *Juniperus horizontalis*, and under the canopies of *Rhus trilobata* and *Artemisia tridentata*.

Nurse crops were not observed with juniper seedlings near Colstrip.

The results suggest that moderate (up to ~ 35%) coverages of competing species do not impede pine establishment and may even have a slightly beneficial effect on seedling growth. Several investigators have reported detrimental effects of competing vegetation on pine seedling establishment (Pearson 1942, Larson and Schubert 1969, Foiles and Curtis 1973, Schubert 1974). In contrast, Burkhardt and Tisdale (1976) reported no suppression of juniper (*J. occidentalis*) seedlings by competing vegetation and that growth rates were positively correlated with the frequency of *Agropyron spicatum* on south slopes in Idaho.

The positive correlation between moderate levels of competing vegetation and height/age ratios of ponderosa pine near Colstrip may be due to the influences of grass or shrub species on seedling microsites. Whitman and Walters (1967) reported that the microclimatic influences of mixed grass prairies are limited to two feet above the soil surface. These influences include greater relative humidity, reduced evaporation and, when associated with a mulch layer, reduced soil surface temperature and increased moisture availability (Hopkins 1954). Shrubs offer similar microsite advantages. The larger leaf surface area intercepts more rainfall and provides more shade, but due to the intense summer thunderstorms in the area most of the intercepted rainfall is probably transported to the soil by stemflow. An alternative explanation for the positive correlation between pine height/age ratios and increasing vegetative cover may be due to pines and

herbaceous vegetation responding similarly to favorable microsites.

The influence of interspecific competition becomes more detrimental in downslope positions where deeper, more developed soils support greater densities of grasses and shrubs. However, the competition does not prevent pine encroachment. Cool season grasses are generally stronger competitors than warm season grasses (Larson and Schubert 1969), but in wet years pine growth is relatively independent of cool season grass competition (Hadley 1969). Encroachment appears to progress more rapidly on coarse textured soils.

#### INTRASPECIFIC COMPETITION

Intraspecific pine competition may be severe in dense stands. Regeneration showed signs of early suppression where mature tree density exceeded 900 stems/hectare. Although several factors may be interacting to cause suppression, root competition may be significant.

Stout (1980) reported that the maximum lateral extension of pine roots near Colstrip was 50 feet; the maximum rooting depths ranged from 11-48 inches, with most roots concentrated in the upper 18 inches. Eis (1978) noted that "overlapping and intermingling of the root systems was the rule" in stands on shallow, rocky soils in British Columbia. Harrington and Kelsey (1979) found seedling roots growing into the outer corky layer of large ponderosa pine roots and attributed small seedling shoots to root grafting. Cox (1959) studied root distribution patterns of ponderosa pine in west central Montana and found 4000-5000 roots from 0.1 to >2.0 inches occupying 10 by 4 foot cross sections of soil columns; approximately 75% of these were found

in the upper 2 feet of soil. Kozlowski and Cooley (1961) found root grafting was more common adjacent to rocks. Stout and Stark did not observe root grafting near Stands 1, 4, and 5 (personal communication, 1981); however, their work was limited to more open portions of the stands. The severity of root competition and its influence on seedling mortality in dense portions of stands near Colstrip is not known.

#### BARE MINERAL SOIL

Bare mineral soil was of minimal importance to seedling establishment. Pine and juniper seedlings were associated with 11% and 14% bare mineral soil within three inches, respectively (Table 3). First year pine seedlings were associated with 11% bare mineral soil; one year olds averaged 19%; and two year olds averaged 22% bare mineral soil. Three year old and older seedlings averaged progressively less bare mineral soil, as would be expected. Vigor (within each age class) was not significantly related to the amount of bare mineral soil. Height/age ratios of pines were negatively correlated with bare mineral soil. Height/age ratios of pines were negatively correlated with bare mineral soil ( $p = 0.01$ ).

Several investigators have emphasized the importance of bare mineral soil for ponderosa pine regeneration (Pearson 1950, Schubert 1974, Foiles and Curtis 1973). However, near Colstrip, unshaded bare mineral soil, especially on southern exposures probably limits germination and growth of seedlings due to high temperatures and droughty conditions. The results of this study are similar to the results Johnsen (1962) and Burkhardt and Tisdale (1976) reported for juniper species (*J. mono-*

*sperma* and *J. occidentalis*, respectively). High soil surface temperatures were cited as the reason for a negative correlation between juniper density and bare mineral soil in southern Idaho (Burkhardt and Tisdale 1976).

In contrast to most of the regeneration studies of ponderosa pine in other regions, pine seedlings near Colstrip were frequently found establishing in 2-3 inches of pine needle litter on north-facing slopes (Figure 6D). Harrington and Kelsey (1979) observed very low germination of ponderosa pine in needle litter in western Montana. They attributed unsuccessful germination to lower temperatures, lack of available moisture in the organic layer, or far-red light (which is proportionally greater under forest canopies) which inhibits the phytochrome system (Harrington 1977). Apparently, pine needle litter does not greatly affect germination and early growth of pines near Colstrip. Some ground litter is probably more favorable to establishment than bare mineral soil near Colstrip, perhaps due to reduced evaporative losses.

#### SEEDLING DENSITY

Stepwise linear regression was used to determine whether the measured variables explained significant amounts of variation in seedling density. In these analyses data from seedling sub-plots were grouped with each associated tree plot.

Several models relating pine, juniper or grouped species density

to independent variables<sup>5</sup> were tried, but none of the models accounted for more than twenty percent of the variability in seedling density. However, several correlations were significant.

Correlation coefficients showed that the same variables that correlate to seedling vigor and height/age ratios correlate to seedling density. The following variables, in descending importance, significantly correlated with seedling density: potential solar radiation (-), basal area (+), percent bare mineral soil (-), percent slope (+), calcareousness (-), percent vegetative cover (+). Potential solar radiation only accounted for 14% of the variability in seedling density.

Most of the independent variables were intercorrelated. On south-facing slopes there is more bare mineral soil, soil surfaces are more often calcareous and support less basal area. The percentages of "competing" vegetation did not significantly differ between north- and south-facing aspects. The positive correlation between basal area and seedling density is probably due to increased shade and increased number of seed sources.

Seedling density of ponderosa pine and Rocky Mountain juniper (Figures 7 and 8) by age or height classes forms typical J-shaped curves. Seedling density by age class is not significantly correlated

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<sup>5</sup> Independent variables included mature tree density, basal area, potential radiation (summer solstice), absolute value of aspect ( $/180^\circ - \text{asp}/$ ), calcareous test (+ or -), percent slope, and percentages of bare mineral soil, rocks, and vegetation on tree plot.



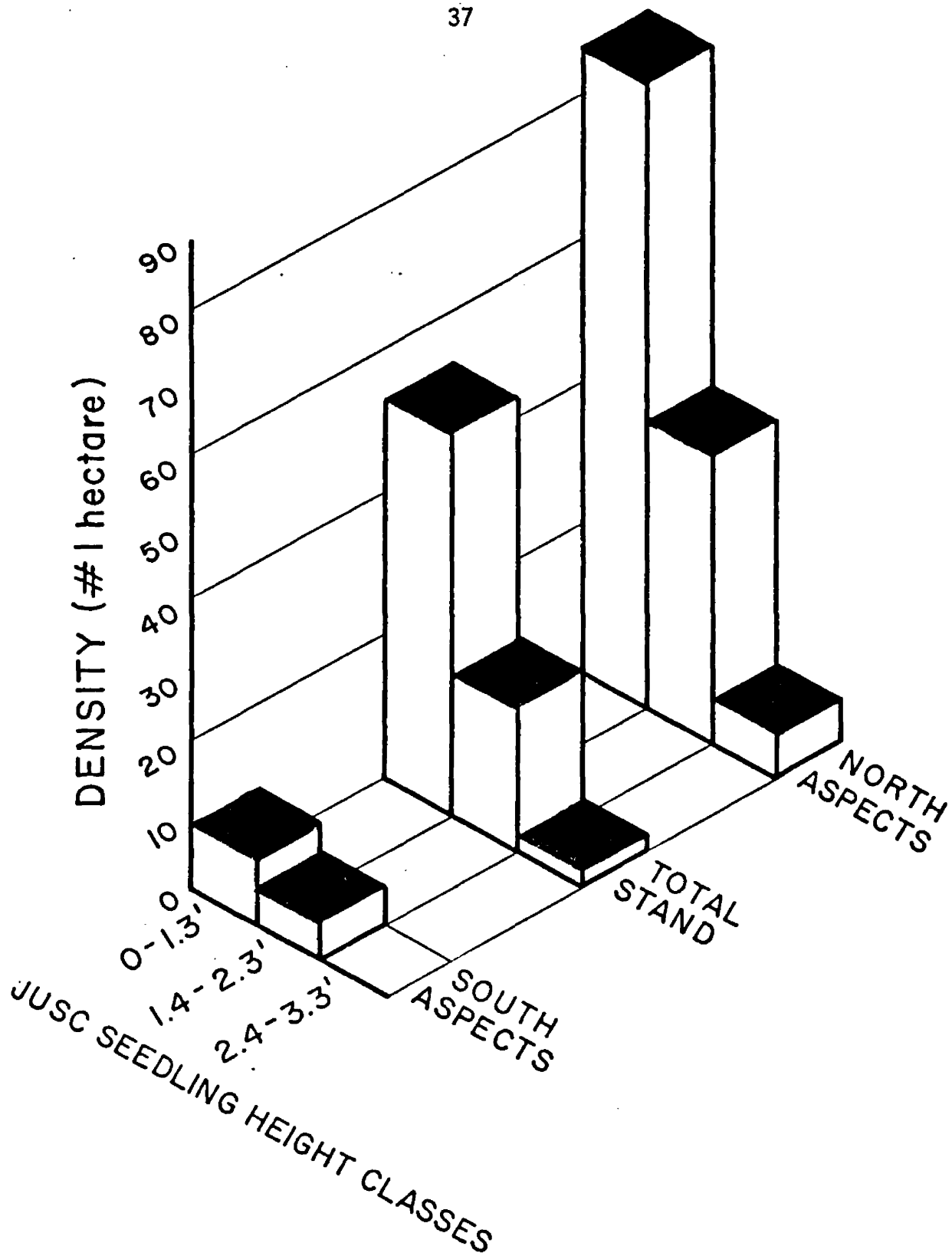


Figure 7. Density of Rocky Mountain juniper seedlings by height class and aspect. South aspects are based on 58 south-facing seedling sub-plots; north aspects are based on 60 north-facing seedling sub-plots; total stand densities are based on 134 seedling sub-plots regardless of aspect.

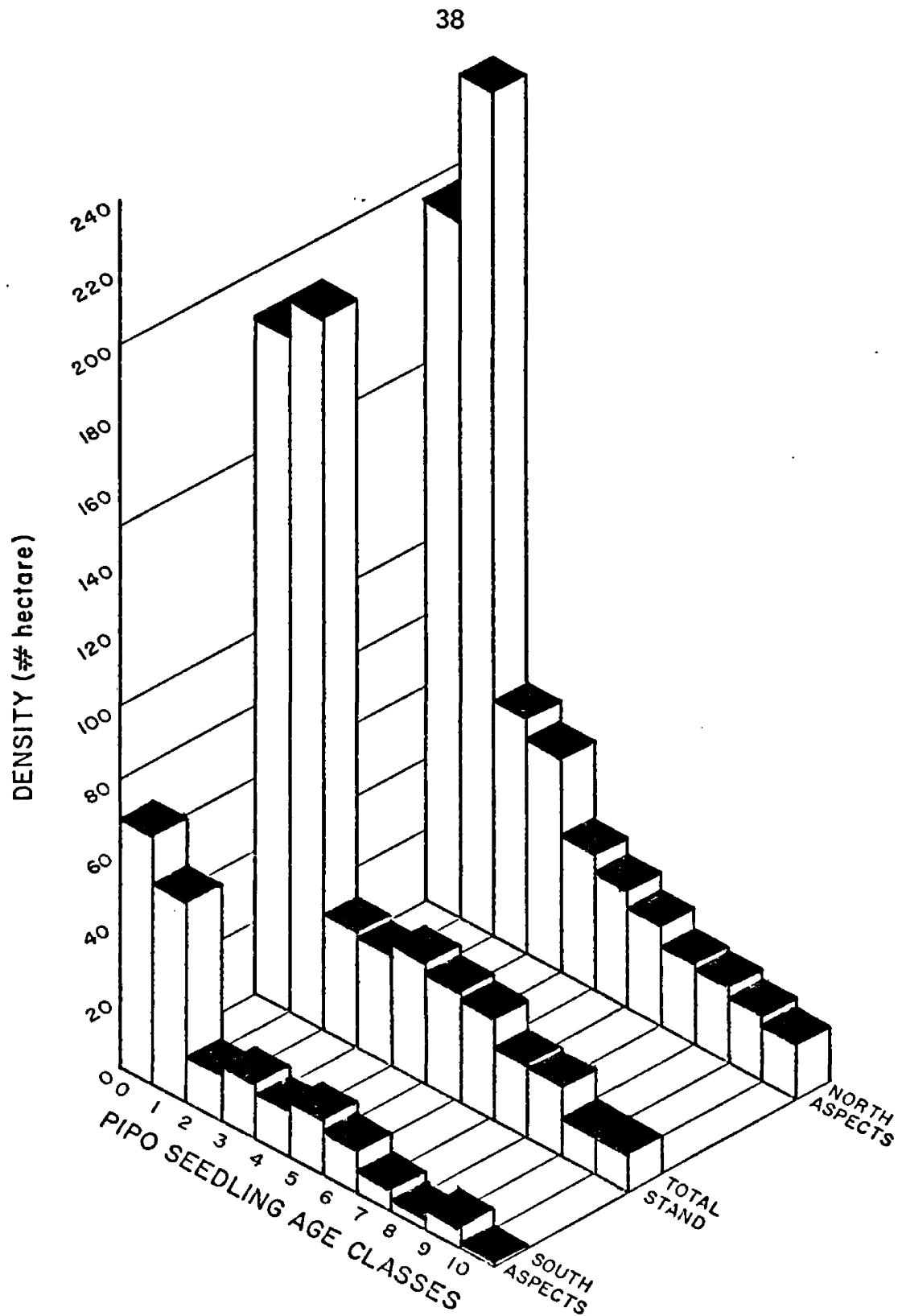


Figure 8. Density of ponderosa pine seedlings by age and aspect. See Figure 7 for sample sizes.

to precipitation even when the high density of first year germinants and one year olds are excluded. Both species had significantly greater ( $p = .05$ ) densities in each class on north-facing than south-facing slopes.

One of the most surprising results of this study was that pine seeds germinated and began to grow in 1979 and 1980. The lowest precipitation on record occurred in 1979 (13.7 cm [5.4 in]) and 1980 was also very low (23.1 cm [9.1]) (see Figure 1). Thus, even when macroclimatic conditions are very unfavorable for seedling establishment, some regeneration occurs on favorable microsites.

Figure 9 shows seedling density by stand, species, aspect, and for the stands as a whole regardless of aspect. Seedling density ranged from 94 seedlings/hectare (38/acre) to 1191 seedlings/hectare (482/acre (Stand 5)). South transects supported lower seedling densities than north transects in all stands except Stand 10 (Figure 9). The comparatively low density of seedlings on the north slope of Stand 10 was probably due to the previously mentioned problem of root competition because 1) several seedlings were initially establishing, and 2) light was adequate for growth.

The greatest overall seedling density (regardless of aspect) occurred in the sandy/rocky soils of Stand 5. Regeneration was largely concentrated on the north sides of trees in this stand. Stand 12 supported dense seedlings which were concentrated in shallow sandy water catchments on massive sandstone, but their growth was poor and the poorly fractured bedrock will probably limit long-term survival

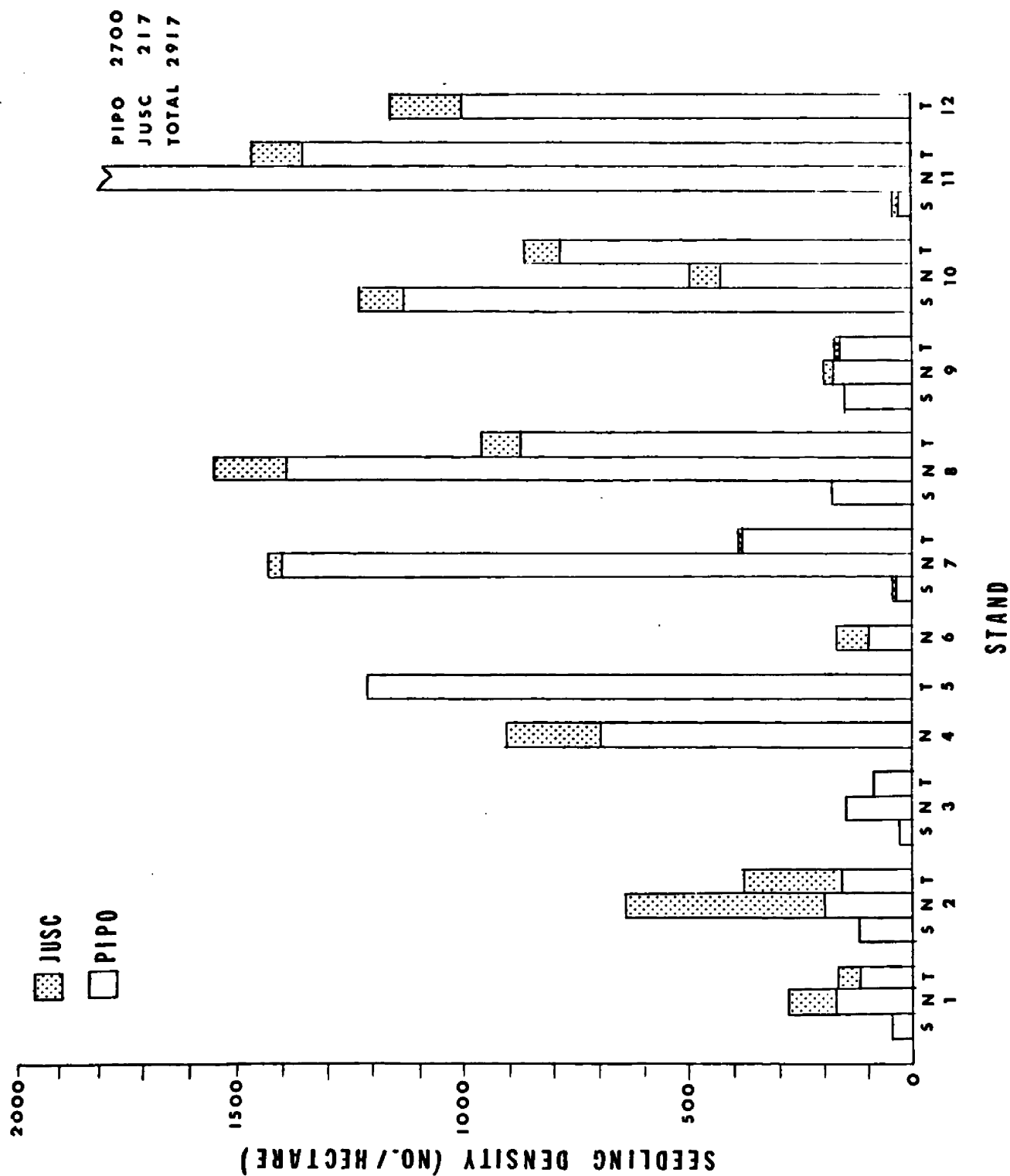


Figure 9. Continuous bar graphs showing seedling density by stand, species, and aspects (S = south facing portions of stands; N = north-facing portions of stands; T = the entire stand regardless of aspect).

of most of the seedlings.

Juniper regeneration was 1) primarily limited to north slopes or more densely forested south slopes (e.g. Stand 10, south transect), and 2) was more abundant where the substrate consisted of deep layered porcelanite (Stands 2 and 4).

#### MORTALITY

Little can be said regarding the amount and causes of mortality because the data were collected in just one field season. However, the age and height class distributions (Figures 7 and 8) and field observations suggest some trends.

Figure 8 shows a dramatic decrease in density (65% decrease) between the one and two year old pines. That this decrease in density represents mortality is based on 1) field observations of several dead first year germinants to two year old pines, and 2) the results of studies on pine mortality. Foiles and Curtis (1965) reported sixty-four percent mortality of ponderosa pine in three years in central Idaho. Heidmann *et al.* (1977) and Pearson (1950) reported that the greatest mortality in ponderosa pine in Arizona occurred within the first two to three years. Near Colstrip the critical period of establishment is also three years (including first year of growth). Density of seedlings greater than two years old remains relatively constant.

Drought and insolation are cited as the two primary causes of mortality in most ponderosa pine regions. Dead seedlings were sometimes observed in 2-3 in. litter under dense overstory canopies in-

dicating that drought from intraspecific root competition may be a common cause of mortality in dense stands. Apparently, seedlings can germinate and survive under dense overstories until their roots contact the zone of mature tree root competition (see Weaver and Clements 1938, Toumey 1929, Aaltonen 1926; for an opposing view see Pearson 1930).

In contrast to ponderosa pine, the height class distribution of juniper seedlings (Figure 7) reflects a gradual increase of the species in natural stands. This conclusion is based largely on the lack of dead juniper seedlings in the area; once established juniper seems to persist. In addition, very few juniper seedlings showed signs of insect or fungal damage.

#### DESTRUCTIVE AGENTS

Pine seedlings were more subject to insect and mammal damage than juniper seedlings. Table 4 summarizes the types of damage that were observed. Sixty-two percent of the pine seedlings and ninety-eight percent of the junipers showed no evidence of insect or other damage. Porcupine damage was not observed on seedlings less than 1.7 feet tall. Little observed seedling mortality could be attributed to insect or mammal damage.

Table 4. Damaging agents on pine (PIPO) and juniper (JUSC) seedlings.

	PIPO	JUSC
n	621	106
Mammals (trampling or porcupine)		
% damaged	3	1
Insects		
Tip Moth*		
% damaged Total	28	0
% light damage	18	
% moderate damage	9	
% severe damage†	1	
Needle miner (%)‡	1	0
Unidentified (%)	4	1

\* *Rhyacionia bushnelli* or *R. neomexicana*

† Terminals completely destroyed

‡ *Coleotechnites* spp.

#### EARLY GROWTH

During the first two years after pine seed germinates, most of the available photosynthate is used for developing the root system (Larson and Schubert 1969a). Stein (1978) reported that ponderosa pine grew longer roots than four other conifer species in the first two years. Whether an individual seedling can meet its genetic potential for rapid growth depends on several factors including the osmotic

stress at the time of germination (Larson and Schubert 1969b), type of soil (Van Haverbeke 1963, Stein 1978, Eis 1978), available soil moisture and soil temperature.

Seedling roots were excavated during the course of this study. The root capacity in moist, coarse-textured soils is very high. Figure 10 shows a group of one year old seedlings that were growing in a shallow, sandy water-catchment over sandstone bedrock. The root:shoot length ratio for these seedlings was 16:1 (64 cm:4 cm). Root:shoot ratios for young pine seedlings in other areas ranged from 6:1 to 13:1. In contrast, Van Haverbeke (1963) reported average pine root penetration of 35 cm in first year seedlings in the Black Hills.

Early juniper growth probably follows a similar pattern to ponderosa pine. Johnsen (1962) reported no increase in juniper seedling height growth for four years (although lateral branches were developing). In the same study he reported juniper roots grew 21.7 cm. in the first three months after germination.

Table 5 shows the mean, ranges and standard errors of pine seedling heights from first year germinants to seven year olds. The data show that the rate of shoot growth generally increases more rapidly after the seedlings are two years old.



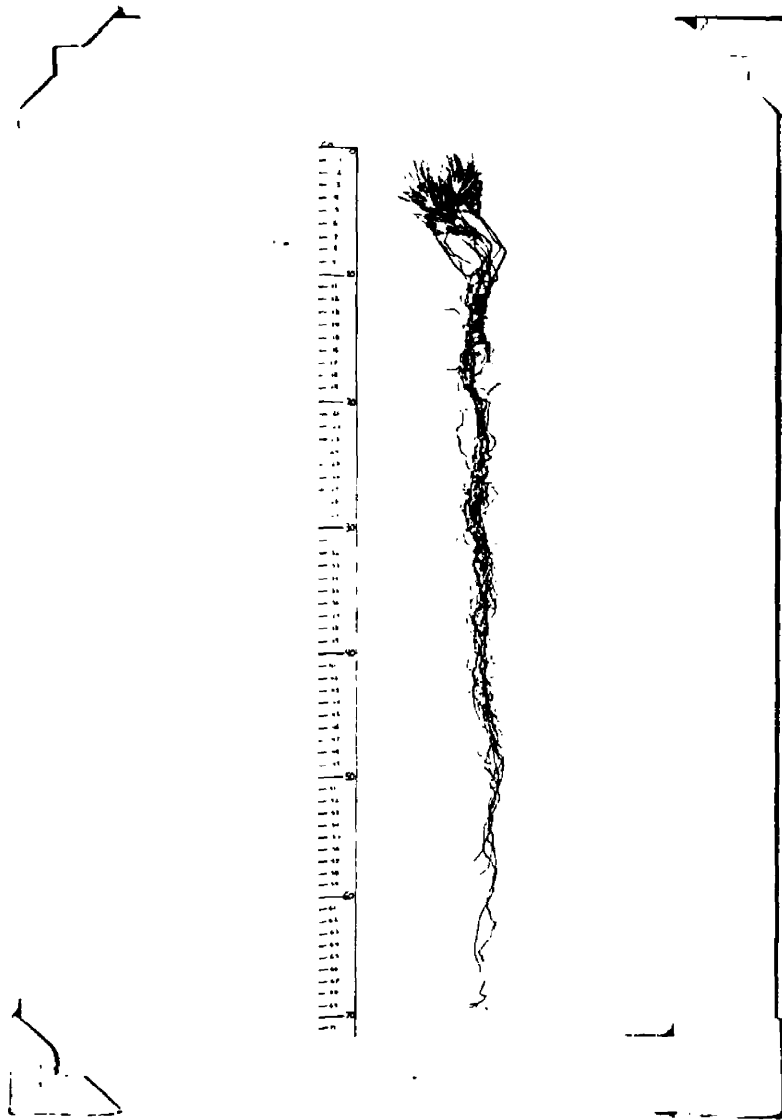


Figure 10. One year old water-cached seedlings grown in shallow, sandy water-catchment over bedrock sandstone. Root:shoot length ratio equals 16:1 (64 cm:4 cm).

Table 5. Mean, range and standard error of heights by age for ponderosa pine seedlings near Colstrip.

Age	n	$\bar{x}$ Height (ft.)	Range (ft.)	St. Error
0	155	0.1	0.1-0.3	0.00
1	134	0.2	0.1-0.3	0.00
2	66	0.3	0.1-0.6	0.01
3	57	0.5	0.2-0.9	0.02
4	34	0.7	0.3-1.4	0.04
5	38	0.8	0.1-2.0	0.06
6	37	1.2	0.4-3.0	0.09
7	23	1.6	0.3-2.9	0.15

## TREES

### STAND STRUCTURE

Ponderosa pine stands near Colstrip generally form all-aged distributions although gaps up to thirty years occurred in some stands. Trees dating to the 1880s were present in most stands (see Appendix A). Figure 11 shows the density of pines by aspect and ten year age classes. Data from twelve stands were grouped in order to present an overall view of the age class distributions by aspect. Only pines greater than one meter tall are included in Figure 11; had seedlings been included the distribution would have resembled a J-shaped curve.

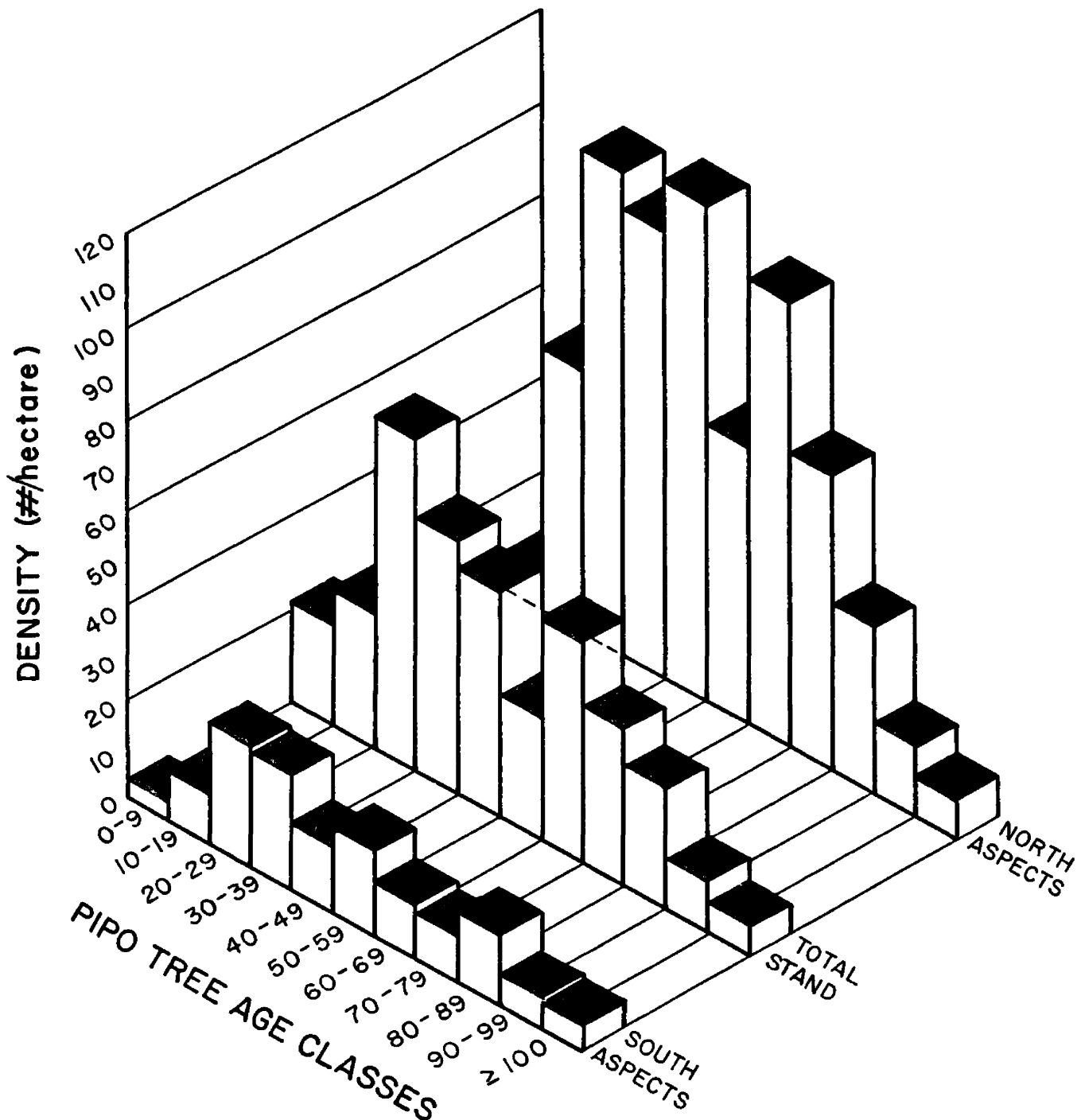


Figure 11. Density of ponderosa pine trees by aspect, total stand (regardless of aspect) and ten-year age classes. Seedlings ( $\leq 1$  meter tall) were omitted from this graph. North aspects are based on thirty tree plots; south aspects are based on twenty-nine tree plots; total stand estimates are based on sixty-seven tree plots.

Pine tree density was significantly greater on north slopes in each age class than on south slopes, except in the oldest age class.

Age class density was regressed over average decadal precipitation to determine whether a significant relationship exists between the two variables. The analysis can be criticized due to the use of means in regression, and due to the small sample size. However, the results suggest that macroclimatic precipitation may explain a significant amount of variability in age class density. Densities of the 0-9, 10-19 and  $\geq 100$  year age classes were omitted in this analysis because I felt the amount of mortality in young and old trees might mask any trend that exists. Based on data from 20-99 year old age classes ( $n = 8$ ) the following results were obtained:

$$T = -86.05 + 9.00P \quad ; \quad r^2 = 0.56$$

$$*DS = -18.21 + 2.41P \quad ; \quad r^2 = 0.37$$

$$DN = -175.58 + 17.73P \quad ; \quad r^2 = 0.68$$

where DT = density within an age class regardless of aspect

DS = density within an age class on south aspects

DN = density within an age class on north aspects

P = mean decadal precipitation (0.1 inches)

$r^2$  = coefficient of determination

\* = not significant at  $p = 0.05$

Decadal precipitation explained 56% of the variation in age class densities regardless of aspect, 68% of the variation of age-class

densities on north slopes, and an insignificant amount (37%) of the variability in age-class densities on south slopes. The results suggest that although seedlings will germinate and begin to grow in very dry years (high densities of 1979 and 1980 germinants), the number of seedlings that survive a decade is related to decadal precipitation. The higher coefficient of determination on north versus south slopes indicates that factors other than precipitation may be more limiting on south slopes (e.g. high surface temperatures, greater evapotranspiration, etc.).

The all-age class distribution of pines suggests the importance of microsites over precipitation and cone crop periodicities in tree establishment. Age cores show that some trees established and survived from every year since 1887 except for one year (1939). Thus, the age-class distribution counters reports from other areas that pine regeneration only occurs when excess precipitation coincides with high seed production and optimum seedbed conditions (Cooper 1960, Meagher 1950, Foiles and Curtis 1973, Schubert 1974).

Junipers form all-aged distributions on north slopes but on south slopes only younger size classes are present. The diameter class distribution is shown in Figure 12. Based on a limited number of juniper cores, trees on south slopes are less than fifty years old (d.b.h. < 4" = < 50 yrs; d.b.h. > 4" = > 50 years). Figure 12 suggests that junipers are gradually encroaching onto south slopes but are limited by site conditions and seed dissemination. As mature

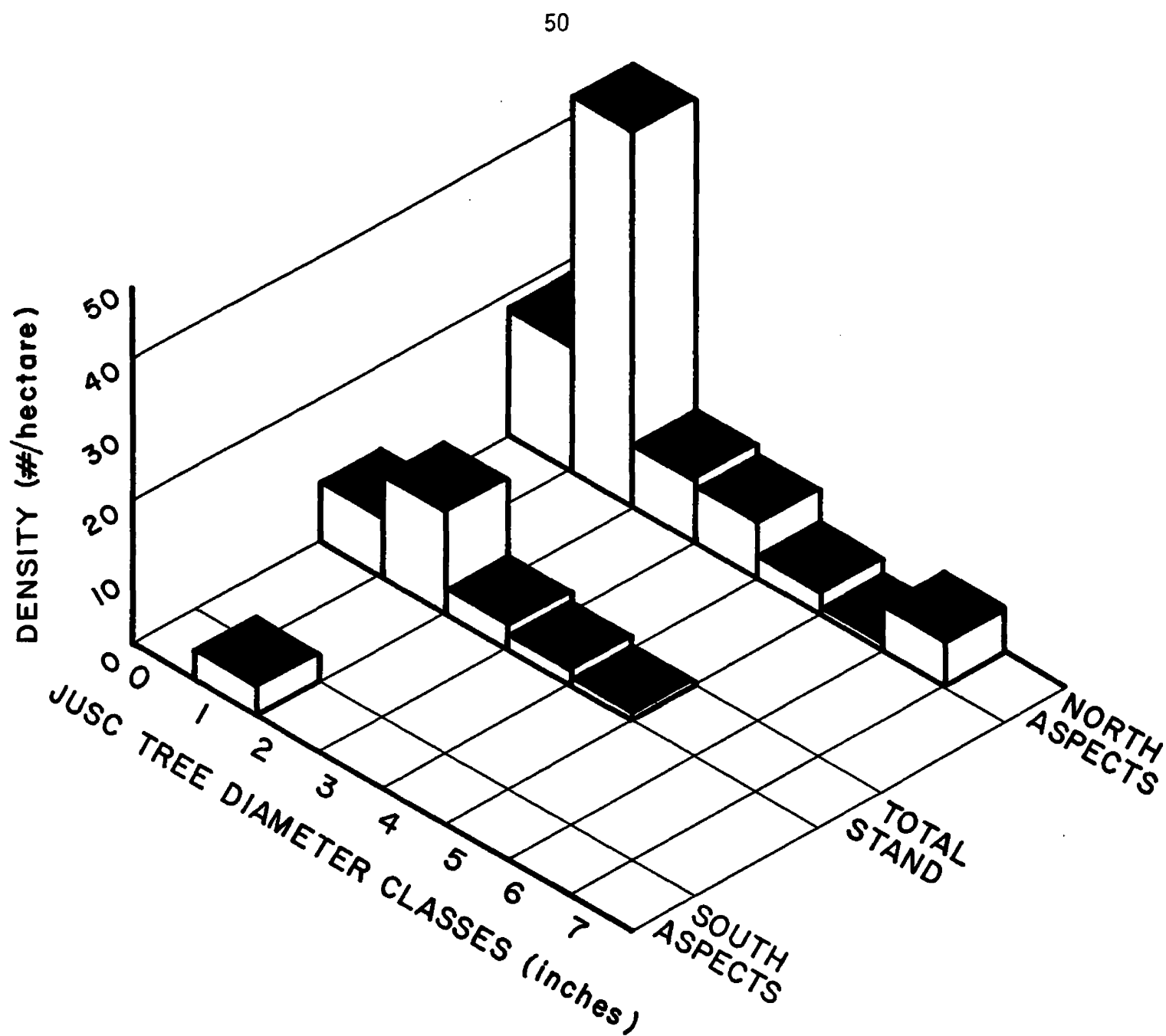


Figure 12. Density of Rocky Mountain juniper trees by aspect, total stand (regardless of aspect) and diameter class. Trees < 4" d.b.h. are less than 50 years old; trees > 4" d.b.h. are greater than 50 years. See Fig. 11 for sample size information.

junipers are gradually established on south slopes the importance of this species in south slope stand composition would be expected to increase.

Jones (1945) reviewed forest stand structure studies throughout the northern temperate zones and noted the rarity of all-aged stands of coniferous species. The three examples he cited were limited to rocky or arid sites in Europe and Japan. Potter and Green's (1964) work in North Dakota suggested an all-aged structure although they reported their results by diameter rather than age classes. Cooper (1961) reported uneven-aged pine stands in Arizona with large gaps in intermediate age classes. The all-aged structure found near Colstrip is probably common on other severe sites in the ponderosa pine range but few studies have been done to verify this.

The cause of the all-aged distribution is closely linked to the pattern of regeneration. Jones (1945), Cooper (1960, 1961) and Watt (1947) discussed regeneration in terms of waves passing in time. As previously mentioned, several observers have reported that a successful wave of ponderosa pine regeneration in other areas occurs only when certain conditions are simultaneously met and that this is a rare occurrence. In wave terminology, the pine regeneration near Colstrip would be likened to waves of lower amplitude (i.e., fewer seedlings) and much higher frequencies (annually). Barring major disturbances, some seedlings survive from each wave thus creating an eventual all-aged structure.

## DAMAGING AGENTS ON MATURE TREES

Table 6 shows the percentages of pines and junipers that were damaged by various agents. Pines were subject to a greater variety and amount of damage than junipers. Damaging agents on pine included pine tip moths, porcupine stripping or girdling, needle miners, pine rust and lightning or mechanical damage. Ten percent of the junipers had light infestations of witches' broom but no apparent insect damage.

Although pine tip moth damage was extensive, most trees only had a few infested buds. Porcupines were a probable cause of death in < 1% of the pines; most of the porcupine damage was not lethal. Cone borer (*Ernobia* spp.) damage was severe in 1979, but very little damage was observed in the 1980 cone crop.

Bromenshenk (1977), who conducted baseline insect-air pollution studies near Colstrip, concluded that southeastern Montana woodlands were "exceptionally free" of insect and disease problems. He listed forty-nine insect species associated with ponderosa pines near Colstrip.

Much attention has been focused on the effects of fluoride and sulfur dioxide on ponderosa pine near Colstrip. Although several studies have reported direct or indirect detrimental effects on pine species at low sulfur dioxide and fluoride concentrations, Gordon *et al.* (1977) and P. Tourangeau (U of M, Missoula, personal communication, 1981) have not yet been able to attribute pine damage to phytotoxic emissions of Colstrip units 1 and 2 (however, data from the last three years have not been summarized yet).



Table 6. Damaging agents on pine (PIPO) and juniper (JUSC) trees near Colstrip.

	PIPO	JUSC
n	597	83
Porcupine	32	0
Pine Tip Moth (%)* (Rhyacionia spp.)	85	0
Needle Miner (%) (Coleotechnitus spp.)	7	0
Rust (%) (Cronartium spp.)	4	0
Lightning or mechanical (%)	1	1
Witches' broom (%) (Gymnosporangium spp.)	0	10
Unidentified (%)	2	1

\* 88% of the trees with tip moth had "light" damage (limited to a few buds only).

## DENSITY AND BASAL AREA

Figure 13 and Appendix B show tree density by species, aspect and stand. Tree density ranged from 59 stems/ha. (24 stems/acre) to 1447 stems/ha. (586 stems/acre). Pine density was consistently greater than juniper density in all stands. Pine density ranged from 59 stems/ha. (24 stems/acre) to 1389 stems/ha. (562 stems/acre); juniper ranged from 0 stems/ha. to 72 stems/ha. (29 stems/acre). Juniper and pine density was significantly greater on north slopes than on south slopes ( $p = 0.05$ ). Basal area (Appendix B) ranged from  $0.90 \text{ m}^2/\text{ha}$ . ( $3.9 \text{ ft.}^2/\text{acre}$ ) to  $13.94 \text{ m}^2/\text{ha}$ . ( $61 \text{ ft.}^2/\text{acre}$ ) most of which was pine basal area.

Regression analysis did not provide predictive models for basal area or density, however, several significant correlations should be mentioned. Both basal area and density were significantly correlated with the age of the oldest tree in the stand (+), percent bare mineral soil (-), potential yearly radiation (-), and calcareousness (-). The first two factors are functions of time; basal area and density obviously increase with time and the amount of bare mineral soil concomitantly decreases. Density and basal area decrease with increasing radiation loads and calcareousness. Percent slope, parent material, percent surface rock and slope position did not significantly correlate with density or basal area.

Table 7 shows basal area and density comparisons between stands. Data were analyzed by one-way analysis of variance (ANOVA) and Duncan's multiple range test. ANOVA results showed that basal area and density of ponderosa pine and combined species had significantly

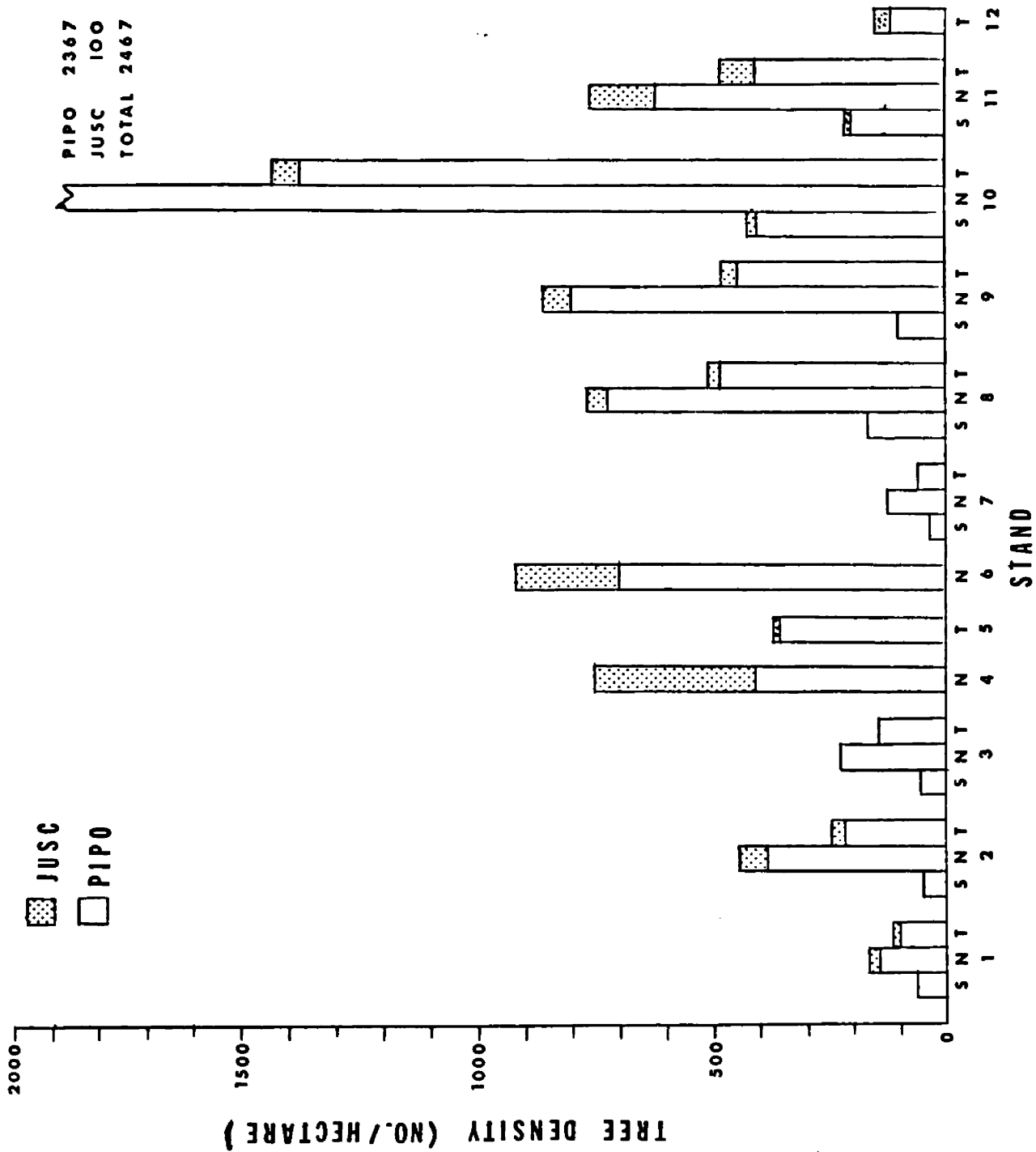


Figure 13. Continuous bar graphs showing the density of trees by stand, species, aspect and for entire stands (regardless of aspect).

Table 7. Stand-by-stand comparisons of tree basal area and density (north and south plots combined).  
Duncan's multiple range comparisons are significant at  $p = .05$ . Stands 4 and 6 were  
omitted because only north slopes were sampled.

STANDS BY INCREASING VALUES											
Total Basal Area (m <sup>2</sup> /ha)	Stand	1	7	2	12	5	3	9	11	10	8
	$\bar{X}$	0.90	2.34	2.89	2.99	5.42	7.17	9.49	9.99	13.16	13.94
	D.M.R.										
Pine Basal Area (m <sup>2</sup> /ha)	Stand	1	7	2	12	5	3	9	11	10	8
	$\bar{X}$	0.89	2.34	2.83	2.93	5.42	7.17	9.49	9.93	13.13	13.94
	D.M.R.										
Juniper Basal Area (m <sup>2</sup> /ha)	Stand	3	5	7	8	9	1	10	2	11	12
	$\bar{X}$	.00	.00	.00	.00	.00	.01	.03	.06	.06	.07
	D.M.R.										
Total Density (#/ha)	Stand	7	1	3	12	2	5	9	11	8	10
	$\bar{X}$	59	118	143	157	249	370	483	489	514	1447
	D.M.R.										
Pine Density (#/ha)	Stand	7	1	12	3	2	5	11	9	8	10
	$\bar{X}$	59	108	121	143	220	361	417	458	490	1389
	D.M.R.										
Juniper Density (#/ha)	Stand	3	7	5	1	8	9	2	12	10	11
	$\bar{X}$	0	0	8	9	24	25	29	36	58	72
	D.M.R.										

greater variation between stands than within stands ( $p = 0.01$ ). Juniper basal area and density did not significantly differ between stands.

The highest tree densities occurred in Stands 8 and 10 (Figure 13 and Table 7), and on the north slopes of Stands 4 and 6 (Figure 13). As the results of regression analysis suggested higher densities in these areas are due, in part, to the length of relatively disturbance-free stand development, lower radiation loads and less calcareous soils. Juniper density was greatest on Stand 4 (north slope; see Figure 13) where all of the aforementioned factors were operant and where the parent material was porcelanite.

#### POTENTIAL PRODUCTIVE CAPACITY

Although timber stands near Colstrip are not of commercial quality, the potential productive capacity of sample stands was estimated 1) for future comparisons between mined land and natural site quality, and 2) to identify high quality sites which can be used as prototypes for rapid tree growth on mined lands. Rapid tree growth is important on mined lands because successful self-regeneration will partly depend on the availability of shaded microsites for tree seedlings.

Height/age ratios were used to compare the potential productive capacity of stands because none of the existing site index curves (Mogren 1956, Hornibrook 1939, Meyer 1938, Lynch 1958, Minor 1964, Barrett 1978, Tesch *et al.* 1980) were applicable to the Colstrip area. To compare potential site quality in stands near Colstrip the means of

the five highest height/age ratios were computed from north aspects, south aspects and from each stand as a whole. Trees less than 20 years old and greater than 100 years old were omitted. To compare early growth between stands, the means of the five highest pine seedling height/age ratios were also computed.

Height/age ratios were analyzed by ANOVA and Duncan's multiple range tests. ANOVA results showed no significant differences between north slope tree and seedling height/age ratios when compared to south slope ratios ( $p = 0.05$ ). However, results showed significant differences between stands ( $p = 0.05$ ).

Table 8 shows the mean height/age ratios of pine trees and seedlings for each stand and the results of Duncan's multiple range tests. Seedlings generally grew at much slower rates than trees because a greater proportion of the photosynthate is utilized for root production in early years of growth (Larson and Schubert 1969a).

Site quality (Table 8) was highest in the coarse-textured, deep, rocky soils of Stands 5 and 8. The most rapidly growing trees in these stands averaged 0.84 feet/year. The poorest site was Stand 12 (0.34 feet/year) which had very shallow soils over massive sandstone bedrock. Regression analysis showed no significant correlation between height/age ratios and potential solar radiation, surface rockiness or percent slope. The relative site quality probably follows a gradient of moisture stress which may in turn be related to interactions between depth of soil, subsurface rockiness, seepage areas or other factors, which were beyond the scope of this study.

Table 8. Stand-by-stand comparisons of site quality based on height/age ratios (feet/year) of pine trees (20-100 years old). Seedling height/age ratios (< 10 years old) are also presented to compare seedling growth rates. Mean height/age ratios followed by different letters are different at the 0.05 level (Duncan's multiple range test).

Mean height/age ratios of each stand													
	Stand	6	9	1	12	10	8	3	11	4	2	5	7
Pine Seedlings	$\bar{X}$	.1641	.2000	.2053	.2370	.2508	.2678	.2767	.3200	.3375	.3478	.3641	.4200
	D.M.R.	a	a,b	a,b,c	b,c,d	b,c,d	c,d,e	d,e,f	e,f,g	f,g	g	g,h	h
	Stand	12	1	7	6	4	9	11	2	3	10	8	5
Pine Trees*	$\bar{X}$	.34	.47	.53	.53	.60	.68	.70	.72	.72	.82	.84	.84
	D.M.R.	a	b	b,c	b,c	c,d	d,e	d,e	e	e	f	f	f

\* When tree data were fitted to Mogren's (1956) site index curves the range in site index was from 31 to 63 (base age = 100 years) but, as mentioned in text, site index curves have limited applicability to stands near Colstrip. [These values refer to the height (in feet) that a dominant tree could reach in 100 years.]

Seedling height/age ratios ranged from 0.16 feet/year (Stand 6) to 0.42 feet/year (Stand 7) (Table 8). Seedlings in Stand 7 grew in unique microtroughs caused by erosion around bunch grasses (see Figure 6C and Appendix A) which probably provided extra moisture. Poor seedling growth in Stands 6 and 9 was probably due to root competition. Poor growth in Stand 1 may have been due to the highly calcareous soils (strong effervescent reaction in all plots).

For reclamation purposes, Stand 5 deserves particular attention. It was the only stand which had consistently rapid growth of both seedlings and trees (Table 8). Seedling growth was rapid in spite of heavy grass coverages. Another indication of the high quality of Stand 5 was found by examining the cores from sample trees. Unlike the cores from pines in other stands, cores from Stand 5 showed little "sensitivity" (Fritts 1976) to droughts in the 1910s and 1930s. Annual growth rings often showed radial growth rates of six rings/inch. The high productivity of Stand 5 may be due to a combination of deep sandy, rocky soils (see also Ffolliot and Baker 1977, Zinke 1958, Pearson 1950) and perhaps a high water table.

#### TREE DIMENSIONAL RELATIONSHIPS

Tree dimensional relationships were investigated to see how strongly age correlates to diameter and/or height of ponderosa pine. If sufficiently strong relationships exist, regression equations could be used to predict or compare heights or diameters of outplantings on reclaimed areas. Unfortunately, the lack of age data on junipers precluded the use of age as an independent variable in this species.



As the previous section indicated height-age relationships vary considerably between stands. When data were grouped from all stands, age only accounted for 72% ( $r^2$  value) of the variability in pine tree heights. In general, the height growth of pines near Colstrip begins to level off when the trees are eighty to ninety years old. Maximum heights were site-specific and ranged from thirty feet on severe sites such as Stand 12 (sandstone outcrop) to seventy-six feet (outside of plots) in Stand 5. This compares to a maximum height of 102 feet for ponderosa pine on the Northern Cheyenne Indian Reservation thirty miles south of Colstrip (Steve Cooper, Forestry Sciences Lab, Missoula, unpublished data). Diameter growth is typically more variable than height growth. Age accounted for only 59% of the variation in pine diameters. Table 9 shows the means and ranges in height and diameter of ponderosa pine by ten year age classes.

When pine heights were regressed over age in individual stands simple linear coefficients of determination ( $r^2$  values) ranged from 0.50 to 0.93. In general, stronger linear relationships existed on sites with higher height/age ratios. Given the stand to stand variability it is impossible to reliably predict height growth of pines on mined lands. However, the results from Stand 5 will be presented to show what may be expected under optimal conditions:

$$\text{height (ft.)} = 2.53 + 0.73 (\text{age})$$

$$\text{s.e.}_{\hat{y}} = 3.76 \text{ ft.}$$

$$r^2 = 0.93$$

$$n = 45 \text{ pines (range in age, 9 to 89 years old)}$$

Table 9. Means and ranges in height and diameter of ponderosa pine trees by ten year age classes.

AGE CLASS	$\bar{X}$ DIAMETER(in.)	RANGE	$\bar{X}$ HEIGHT(ft)	s.e.	RANGE
10 - 19	1.1	0.0 - 3.0	6.2	.33	3 - 24
20 - 29	2.2	0.0 - 7.0	9.8	.47	3 - 27
30 - 39	3.1	0.0 - 9.0	12.7	.83	4 - 30
40 - 49	3.9	0.0 - 11.0	15.5	.91	4 - 32
50 - 59	6.4	1.0 - 13.0	24.7	1.24	9 - 46
60 - 69	7.8	1.0 - 16.0	28.8	1.15	9 - 55
70 - 79	9.7	1.0 - 20.0	35.4	1.33	6 - 58
80 - 89	11.9	4.0 - 17.0	38.7	1.74	14 - 58
90 - 99	11.4	6.0 - 17.0	35.5	2.44	20 - 49
$\geq 100$	11.2	5.0 - 20.0	33.0	3.30	12 - 60

Moisture stress limits both height and diameter growth (Fritts 1976). Running and McCann (1980) reported seasonal predawn plant moisture stress of pines ranged from -7 bars to -22 bars between June and August of 1980 (measured 3-5 feet above ground level). Water stress in the upper canopy of a sixty foot pine is roughly four bars lower (-11 to -26) (Wilson 1970) due to hydrostatic gradients and frictional shear stress. Water potentials of -15 or lower can reduce cambial and apical growth through several possible pathways (Fritts 1976) and is often suggested to directly limit height growth in semi-arid areas.

Preliminary data presented by Running and McCann (1980) showed higher plant moisture stress in pines and junipers growing on regraded mine soils than on natural sites during mid-summer months. If further water stress studies show similar differences then much slower rates of growth may be expected on mine soils.

## FIRE HISTORY

Several investigators have emphasized the importance of fire in ponderosa pine stands (Weaver 1967, Wright 1978, Cooper 1960, Arno 1976, Davis *et al.* 1980, Mueggler 1976). Average fire intervals, the number of years between successive fires, range from 6 to 11 years in pre-settlement ponderosa pine communities in the Bitterroot Mountains in western Montana (Arno 1976) and from 5 to 12 years in Arizona and New Mexico (Weaver 1951). Most investigators have suggested that frequent fires thin stands, reduce dry fuel, and prevent stand-destroy-

ing high-intensity fires (Weaver 1947, 1951, 1967, Arno 1976, Davis *et al.* 1980, Wright 1978). Cooper (1960) emphasized the importance of fire in creating even-aged groups (rarely greater than 0.2 hectares (0.5 acres)) of reproduction in Arizona.

Fire history of stands near Colstrip was studied to see if strong relationships existed between stand structure and fire frequency. The results, shown in Tables 10 and 11, are tentative due to two limitations. First, fire scar wedges were only obtained on six out of the twelve stands due to blizzard conditions late in the field season; in the remaining six stands, fire scar dating was limited to cores taken adjacent to "cat faces". Wedges were taken at stands where previous work showed the most frequent occurrence of fires, so this limitation may not be too serious. The method used in each stand is listed in Table 10. The second limitation is that the low density of herbaceous vegetation may not have caused intense enough fires to scar pines, thus, in some areas the fire frequencies may be underestimated.

Resistance (i.e. survival) to fires varies with species and age of trees. Mature pines are considered highly resistant to fires due to the insulative properties of the bark; the tendency for the bark to flake off when heated; open, loosely arranged needles; and the tendency to self-prune in dense stands. Pine seedlings are more susceptible to fire but are more resistant than seedlings of other species because their buds are protected and they develop corky bark at an early age. Thus, some seedlings can survive low intensity fires when the cambium is not entirely destroyed (Gartner and Thompson 1973).

Table 10. Fire frequency, mean and ranges of fire intervals (# of years between fires) on south and north transects of each stand.

STAND, TRANSECT	FIRE FREQUENCY *	MEAN FIRE INTERVAL (F.I.) <sup>†</sup>	RANGE F.I.	METHOD <sup>‡</sup>
1 S	0/87y/0.7 ha.	-	-	-
1 N	0/87y/0.7 ha.	-	-	-
2 S	1/92y/0.8 ha.	-	-	W
2 N	8/150y/1.0 ha.	13 yrs.	5-28	W
3 S	0/87y/1.5 ha.	-	-	-
3 N	6/92y/2.4 ha.	12 yrs.	3-28	W
4 N	1/194y/2.3 ha.	-	-	W
5 T	1/89y/2.0 ha.	-	-	W
6 N	0/103y/1.5 ha.	-	-	-
7 S	0/90y/2.4 ha.	-	-	-
7 N	1/90y/2.4 ha.	-	-	C
8 S	0/98y/1.6 ha.	-	-	-
8 N	2/188y/1.5 ha.	155 yrs.	155 yrs.	W
9 S	1/88y/1.0 ha.	-	-	-
9 N	3/79y/1.2 ha.	18 yrs.	5-30	W
10 S	3/173y/2.3 ha.	42 yrs.	13-70	W
10 N	2/93y/2.3 ha.	13 yrs.	13	W
11 S	0/93y/1.4 ha.	-	-	-
11 N	0/85y/1.4 ha.	-	-	-
12 T	1/159y/1.2 ha.	-	-	-

\* Fire frequency is the number of fires/age of the oldest tree sampled/area in hectares.

† Fire interval is the number of fires between two successive fires; the mean fire interval is the arithmetic average of all fire intervals throughout a designated time period in a designated area (Romme 1980).

‡ W = fires dated from cross-sectional wedges across the scarred surface

C = fires dated from fire cores taken adjacent to fire scars

- no evidence of fires found i.e. no "cat faces" and no embedded fire scars found

Table 11. Years in which fires occurred on each stand. "X" denotes north transect; "0" denotes south transect; "+" means aspect was not well defined (undulating).

STAND	YEARS																		
	1800	'10	'20	'30	'40	'50	'60	'70	'80	'90	1900	'10	'20	'30	'40	'50	'60	'70	'80
1																			
2								X			X		0	X	X	X	X	X	
3										X				XX	X		X	X	
4														X					
5																	+		
6																			
7																	X		99
8		X																X	
9														X			X <sub>0</sub>	X	
10							0							X <sub>0</sub>	X <sub>0</sub>				
11																			
12								+											

Junipers are far less resistant to fire due to their thin bark, dense canopy and small size (Davis *et al.* 1980). Burkhardt and Tisdale (1976) reported that all junipers less than fifty years old tended to perish in fires. The problem of encroachment of junipers on western rangelands is frequently attributed to the lack of fires (Burkhardt and Tisdale 1976).

Fewer scars were found on south-facing aspects than on north-facing aspects (Tables 10 and 11). The findings agree with Laven *et al.* (1980) and are probably due to the greater amount of bare mineral soil and exposed rocks on south slopes which prevent fires from being carried into the trees.

Fire frequency ranged from 0 fires/103 years/1.5 ha. to 8 fires/150 years/1.0 ha. The mean fire interval for stands which showed evidence of at least two fires was 48 years (range 12 to 155 years). These results compare favorably to the mean fire interval Laven *et al.* (1980) reported for the Front Range in Colorado (46 years) and are far greater than that which Arno (1976) and Weaver (1967) reported for pre-settlement periods.

The influence of fires on stand structure near Colstrip is subtle. The data clearly show encroachment of young pines and junipers in down-slope positions within the last century. But previous regeneration survived in spite of low intensity fires in many stands.

Cooper (1961) reported fire-caused, even-aged groups of pines in Arizona pine forests; however similar patches were not evident near Colstrip. Small even-aged patches (~ 0.03 ha.) were occasionally ob-

served, but evidence did not suggest that they originated from fires.

The gaps in pine age-class distribution that occurred in some stands were not usually attributable to fire history. Ten-to thirty-year gaps in age-class distributions on Stands 1, 5, 6, 7, and 12 (Appendix A, Figures 14, 18, 19, 20, 25) were not explained on the basis of fire scars. The cause of these gaps is unknown. The north slope of Stand 3 exhibited a possible age-class distribution - fire frequency relationship. Four fires occurred on the north slope of the stand between 1932 and 1958 and no trees successfully established during that interval.

All-aged distributions were found in some stands in spite of fires. In most cases (Stands 4, 8, 9, 10, 11), the fire frequency was low. However, Stand 2 (north slope) was anomolous in that it had the highest fire frequency, an all-aged distribution of pines, and junipers up to 4 inches d.b.h. Six fires were recorded on the north slope between 1928 and 1969. However, the scarcity of double scars and wide spacing of scarred trees suggests that each fire was limited to a small portion of the north slope.

In summary, fire does not appear to strongly influence the overall stand structure near Colstrip. All-aged distributions occur with or without detectable fire influence, and gaps in age-class distribution cannot always be attributed to detectable fires. The results are similar to those reported by Laven *et al.* (1980) in the Front Range of Colorado. Low fuel loadings, sparse vegetation, frequent rock outcrops



and bare mineral soil limit the extent and intensity of fires in most stands. Stand-replacing fires are probably unusual (although one occurred several miles north of Colstrip in 1974), but the conditions on the north slope of Stand 6 and in Stands 8, 9, and 10 are such that intense fires may occur within the next few decades.

The preceding discussion of fire history is limited in a long-term historical sense. Only one fire was evident from pre-settlement times (Stand 8, 1810). However, the lack of old fire-scarred pines and the lack of any sample trees previous to 1787 indicates that pines may have increased significantly in the last two hundred years.

Previous to white settlement several factors may have checked the encroachment of pines and junipers. Lightning fires and fires set by Native Americans (Raynolds 1967, Nelson and England 1977) were probably much more frequent than in post-settlement times. In contrast to cattle or sheep grazing, bison grazing was transient (England and DeVos 1969). Therefore reduction of fire fuels and adverse effects on vegetation would have been temporary. Vegetation could recover and another cycle of burning could take place.

Pollen and phytolith analyses (Moody 1972) at an archaeological site near the Peabody mine south of Colstrip indicate that pine and juniper have increased in the area within the last 200 years. Her work suggests that some pine was also present previous to 1700 (perhaps dating to A.D. 700  $\pm$  100, but unfortunately not enough pollen was extracted for accurate carbon dating). Until settlement times the pines were probably limited to the most fire-protected sandstone outcrops.

## SUMMARY AND CONCLUSIONS

### SEEDLINGS

1. Natural upland ponderosa pine and juniper regeneration occurs every year in relatively low densities.
2. Successful regeneration occurs in a variety of microsites. Eighty-nine percent of the pine seedlings and all of the juniper seedlings received partial shade with average reductions of solar radiation of thirty-two percent and forty percent, respectively. Porcelanite mulch, sandstone rocks, microtopographic water catchments, and small draws also provided favorable microsites.
3. Seedling density increased with 1) decreased solar radiation, 2) increased basal area, 3) decreased bare mineral soil, 4) decreased calcareousness, and 5) increased vegetative cover (up to ~ 35%). Percent slope and percent surface rocks did not significantly correlate to seedling density, however seedlings were frequently distributed around exposed rocks.
4. Most pine mortality occurs within the first three years. Drought, insolation and root competition are probable causes of mortality.
5. Pines and junipers are gradually encroaching into downslope grassland areas although the density of pine seedlings was not significantly correlated to slope position.

TREES

1. Stands are primarily all-aged near Colstrip, although gaps of ten to thirty years occur in some stands. Gaps in age-classes did not consistently correlate with fire history, although low-intensity fires could not be detected unless they were severe enough to scar the cambium. Fire frequency ranged from 0/103 years/1.5 ha. to 8/150 years/1.0 ha. Rock outcrops, sparse vegetation and low fuel loadings may account for the relatively low fire frequencies.
2. Tree density ranged from 59 stems/ha. to 1447 stems/ha., most of which was pine. Density was significantly correlated to the oldest tree in the stand (+), potential yearly radiation (-), and calcareousness (-) (the latter was not significantly correlated to juniper density). Basal area ranged from 0.9 m<sup>2</sup>/ha. to 13.94 m<sup>2</sup>/ha. Juniper basal area was very low in all stands. Ten year age-class densities significantly correlate to average decadal precipitation.
3. Height/age ratios were high for both seedlings and trees on deep, sandy/rocky soils of Stand 5. Maximum height/age ratios for pine seedlings and trees were 0.42 and 0.84 feet/year, respectively. Height/age ratios did not significantly correlate to solar radiation, surface rockiness, percent slope or parent material.

4. Age of pine trees accounted for only 72 percent of the variation in height. Tree rings showed great sensitivity to annual moisture conditions (except in Stand 5) and both diameter and height growth are probably limited by moisture stress.
5. Ponderosa pine and Rocky Mountain juniper are within 200-300 miles of the northeastern extent of their range. Their distribution near the limits of their range is topo-edaphically controlled by rocky substrates where moisture is available to trees but less available to grass species. In a long-term sense, the elimination of rocks in the substrate may shift the competitive advantage to other life forms. The gradual encroachment of seedlings into finer textured soils in downslope positions indicates that trees may be able to survive in the non-rocky substrates of mined lands, however, this will probably require long-term "assistance" from land managers.

#### RECOMMENDATIONS

The results of this study suggest the use of techniques that should enhance initial establishment. The suggestions should be tested on field plots to determine the optimum combination of techniques to insure survival at minimum expense.

1. Provide shade for at least the first three years of growth. Based on naturally established pine seedlings, the optimum amount of radiation in midsummer is  $21,000 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  for first-year germinants,  $27,000 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  for one to

three year old seedlings, and  $30,000 \text{ kJ/m}^{-2}/\text{day}^{-1}$  for seedlings from four to ten years old. The values correspond to 50%, 70% and 75% full sunlight on flat ground and should be adjusted by using Figure 7 for the slope and aspect of the planting site. Evidence suggests that juniper seedlings could benefit from greater amounts of shade. Shade cards are probably the most cost-effective means for providing shade.

2. Placing rocks around seedlings, applying a thin (1-2") layer (rock mulch) of small (1-3") pieces of porcelanite at the planting site, and/or incorporating more rocks (arbitrarily ~ 30% by volume) in the topsoil should increase moisture availability to seedlings and prevent competition from very dense competing vegetation (> 35%) that may otherwise develop around seedlings.
3. Small amounts of coverage from non-tree species ( $\leq 35\%$ ) within a foot of planted seedlings should not affect seedling survival and may even enhance seedling microsites by providing light shade and slightly higher relative humidity. If seedlings are planted on sites with dense established cover (> 35%) within 1 foot of the seedlings, light scalping around the planting spot may benefit the seedling.
4. Microtopographic (small depressions about 1' x 1' x .5') alteration should benefit seedlings by providing small water catchments.

5. Optimum seedling container size should be determined.  
Natural root:shoot length ratios range from 6:1 to 16:1 on one year old pine seedlings, suggesting tubes longer than 8 inches may enhance survival.
6. Plantings should be started on north-facing slopes with coarse textured soils. To mimic the natural patterns of regeneration and stand structure some trees should be planted on the same site each year, at least until the earliest plantings produce cones. On north slopes seedling densities of approximately 25 pines/hectare/year should be sought. Thus, if 65% mortality is assumed, planting rates should be roughly 70 pines/hectare/year. Obviously, if shade, rock mulch, and/or microtrough treatments improve survival rates, fewer trees would need to be planted each year.
7. When the earliest plantings reach reproductive age, field surveys should be periodically conducted to see if adequate natural regeneration is occurring. If not, additional planting may be required.
8. Initial plantings should be widely spaced (11 x 11 meters to 12 x 12 meters) and subsequent plantings should be planned to maintain wide spacings so that shade from established trees is dispersed throughout the planting site when older trees reach reproductive age.

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**APPENDIX A**

**Individual Stand Descriptions, Structure and Patterns of Regeneration**

## Stand 1

Location: T2N, R41E, SE1/4, Sec. 32

Habitat Subtype: Ponderosa pine - Big Sagebrush (125)

Stand 1 occupied 1.4 hectares on a gentle ridgeline with a maximum relief of eighteen meters. The oldest tree sampled on the stand was eighty-eight years old and no evidence was found to indicate that trees were established on the site previous to the early 1890s. Parent material consisted of fine sandstones and small amounts of platy shale. No evidence of fire or logging was detected within the stand.

Stand 1 is a harsh, marginal site for tree establishment and growth. It supported the lowest overall (north and south transects combined) basal area and the second lowest seedling density, tree density and height/age ratios of the sample stands. The south transect was particularly severe. The slopes ranged from 18-50% and the aspects were close to due south (mean absolute value of aspect = 13°). The yearly total radiation was the highest estimated for any of the south transects (10,077,656 kJ/m<sup>2</sup>/year).

Several other characteristics distinguish this stand from the others sampled. It was the only stand that had a greater percentage of older trees occupying the south slope (see Figure A1); it had the greatest bare mineral soil (30-50% on sample plots); both slopes were calcareous; and the scanty (< 10%) tree cover was associated with scattered halophytic species (e.g., winter fat (*Ceratoides lanata*)).

Regeneration was greater on north transects than on south transects for both Rocky Mountain juniper and ponderosa pine. On south exposures the limited regeneration was associated with platy shale colluvium or microdraws; regeneration on the north slope was associated with shade from saplings which reduced solar radiation by about 50%.

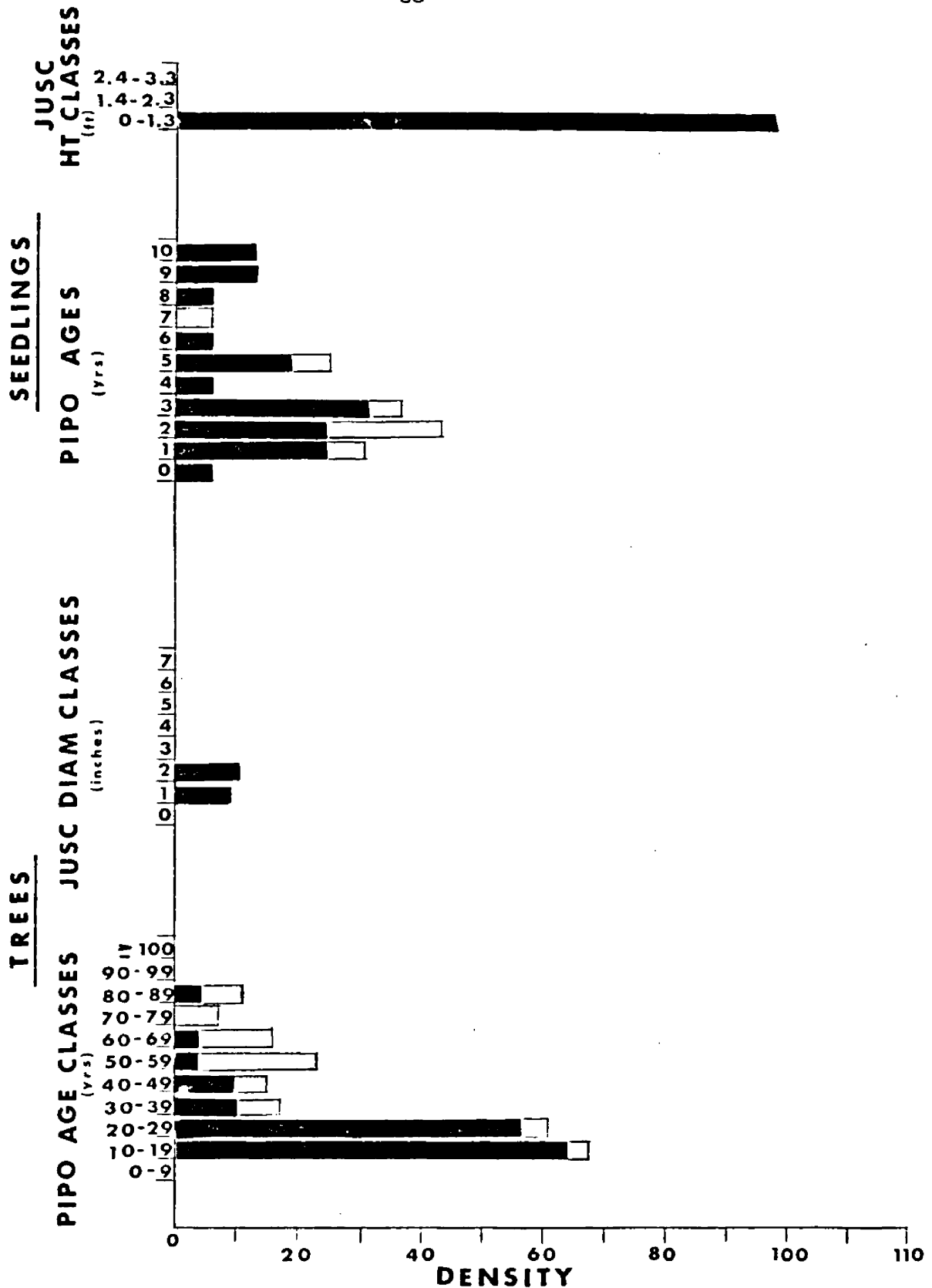


Figure 14. Structure of Stand 1. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of seedlings and trees by age, height or diameter classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 2

Location: T1N, R41E, SE1/4, Sec. 1

Habitat Subtype: Ponderosa pine - Grass (123), South

Ponderosa pine - Juniper (122), North

Stand 2 occupied a 1.8 hectare knoll of fine sandstone and procelanite east of an intermittent tributary of Cow Creek. Maximum relief is approximately twenty-one meters. Only small areas in the stand were calcareous.

The south facing area supported scattered individuals of ponderosa pine (B.A. =  $1.49 \text{ m}^2/\text{ha}$ ; Density = 57/ha.) with traces of *Yucca glauca*, *Rhus trilobata* and *Xanthocephalum sarothrae*. The vegetation was dominated by bluebunch wheatgrass, western wheatgrass and needle-and-thread, but the grass cover was broken with large areas of bare mineral soil.

Northern exposures supported more vegetative cover and was dominated by ponderosa pine (B.A. =  $4.18 \text{ m}^2/\text{ha}$ .; Density = 383/ha.), Rocky Mountain juniper (B.A. =  $0.11 \text{ m}^2/\text{ha}$ .; Density = 58/ha.), and *Rhus trilobata*. Age class distribution was typical of most stands except for the lack of trees over 70 years on the north slope (see Figure A2).

The oldest tree found in the stand was established in 1830. Fire scar dating on that tree and others in the stand indicated that eight fires had occurred on the north exposure (~ 1.0 ha.) within the last 150 years with a mean fire interval of 13 years. The range in fire intervals was from 5 to 28 years. Only one fire scar was found on the

south side of the stand (~ 0.8 ha.). The oldest tree found was 92 years old, therefore the fire frequency for this area is 1/92 years/0.8 ha.

Moderate regeneration of ponderosa pine occurs on both north and south facing slopes (Figure A2). On south slopes the regeneration was limited to 1) upper slope microsites with surface gravels and overstory shade, and 2) a water receiving basin downslope from the primary ridge. In the latter microsite, seedling height growth was relatively high (~ 0.3 ft/yr). North slope pine regeneration was associated with shade and was occasionally found establishing under the canopy of *Rhus trilobata*. Juniper reproduction was limited to shaded portions of the north slope and was denser than on all other stands (450/ha.).

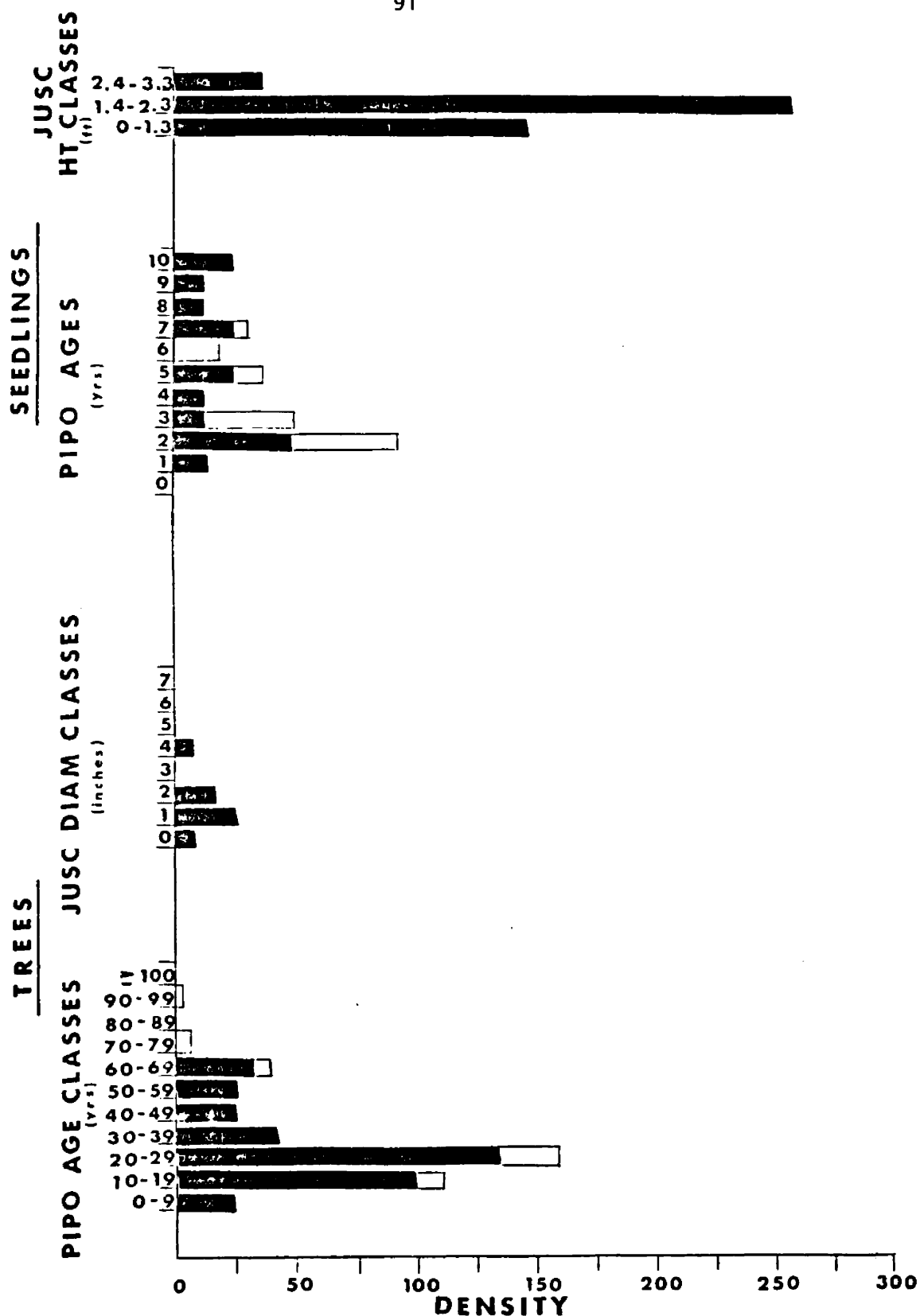


Figure 15. Structure of Stand 2. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of seedlings and trees by age, height or diameter classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

### Stand 3

Location: T1N, R41E, SE1/4, Sec. 1

Habitat Type: Ponderosa pine - Deciduous shrub (124)

Stand 3 occupied a 3.9 hectare west-east ridge with porcelanite and sandstone parent materials. Maximum relief was eighteen meters; slopes averaged twenty-five percent.

Northern exposures supported much more ponderosa pine basal area, density and regeneration than southern exposures (B.A. = 13.13 m<sup>2</sup>/ha; tree density = 230/ha; seedling density = 156/ha). Understory species were dominated by *Rhus trilobata* and *Agropyron spicatum*. The age class distribution (see Figure A3) shows a lack of ponderosa pine in the twenty to forty-nine year, age classes and an overall absence of juniper. This is readily explainable when the fire history of the stand is considered. Fire scar evidence shows five fires occurred on the north slope from 1932 through 1965 which essentially prevented establishment. Only one previous fire was evident on the north slope (1904). The overall fire frequency was 6/92 years/2.2 ha.

In contrast to the north slope, the south slope showed no evidence of fires in the past eighty-seven years (oldest tree sampled). That most of the ponderosa pines on the south slope were less than fifty years old (Figure A3) suggests relatively recent encroachment into the more xeric areas. Species associated with ponderosa pine on this slope were also more xeric (*Yucca glauca*, *Opuntia polycantha* and *Scirpus scoparium*). In spite of the xeric conditions, the ponderosa pine on the south slope had the highest ht/age ratios of any south-



facing slopes (.64 ft/year). The south slope also had the greatest percentage of exposed rocks (13%) of all south slopes.

Compared to other stands Stand 3 had minimal regeneration. On the south slope regeneration was limited to rock outcrops or shaded portions of small west-facing ridge spurs. North slope regeneration included a trace of juniper (not in sample plots); ponderosa pine seedlings were associated with shallow, moist, shady draws, and exposed bedrock.

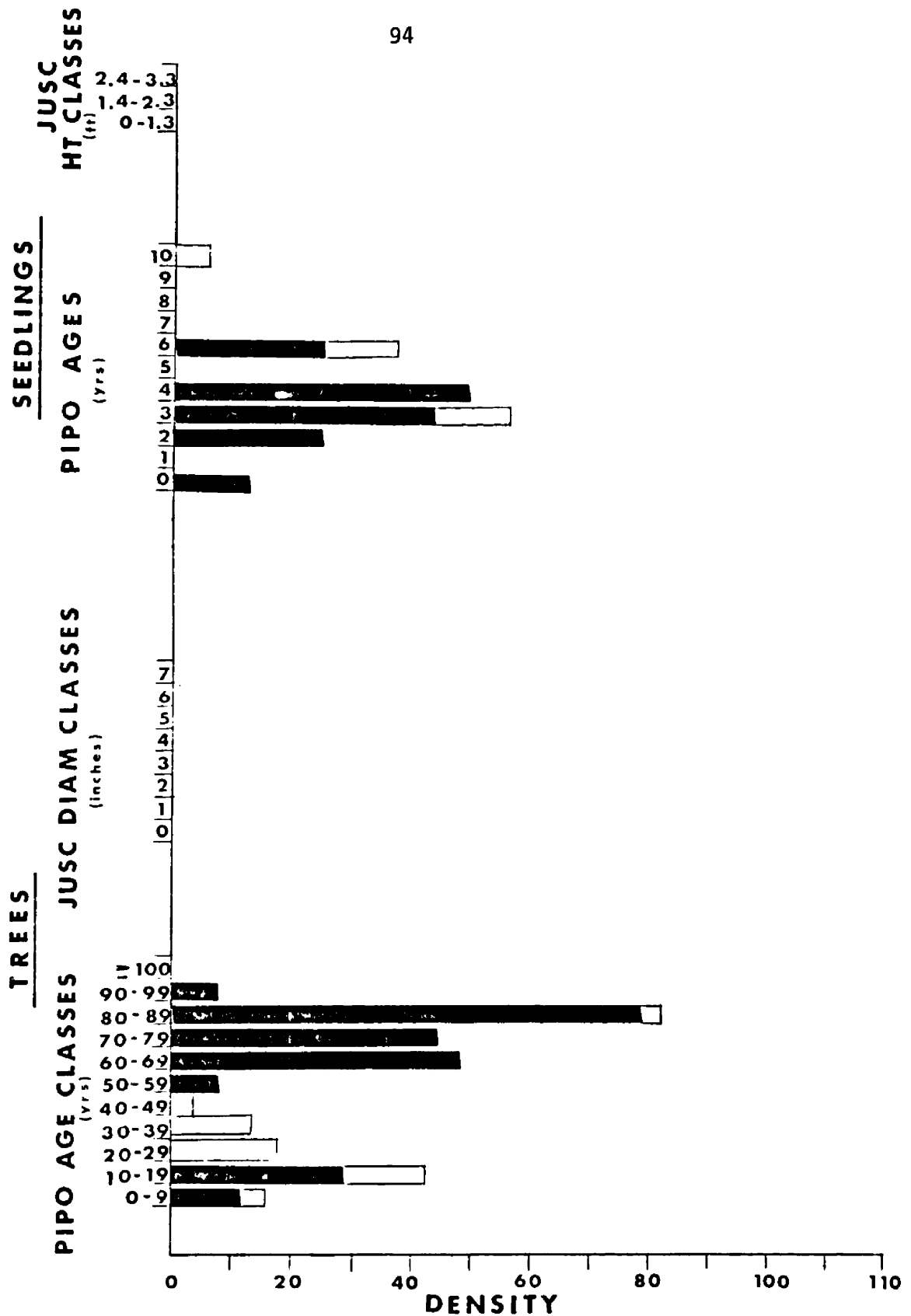


Figure 16. Structure of Stand 3. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of ponderosa pine trees and seedlings. Juniper was not present in the stand. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

#### Stand 4

Location: T1N, R41E, SW1/4, Sec. 30

Habitat Subtype: Ponderosa pine - Juniper (122)

Stand 4 occupied 2.3 hectares on a northeast slope of a ridge with porcelanite parent material and maximum relief of 24 meters. The southwest exposure was excavated for porcelanite, therefore no exposure comparisons were available.

The overstory was dominated by ponderosa pine (cover = 60%; density = 408/ha.; B.A. =  $7.57 \text{ m}^2/\text{ha}$ ) and some Rocky Mountain juniper (cover = 10%; density = 350/ha.; B.A. =  $0.69 \text{ m}^2/\text{ha}$ ). The oldest tree was established in 1796. Fire scars indicate a portion of the stand burned in 1931.

Although more fires probably occurred during the last 194 years, the all-aged distribution of pine and juniper (see Figure A4) suggests that fire was not an important factor in this stand during the twentieth century.

The understory was poorly developed. Relatively mesic shrubs (*Amelanchier alnifolia*, *Prunus virginiana* and *Symphoricarpos occidentalis*) occupied shallow draws. Scattered grasses (mostly *Agropyron spicatum* and *A. smithii*) occupied convex and flat portions of the slope.

Ponderosa pine and juniper were encroaching downslope into sagebrush and grassland areas. Senescent *Artemisia cana* and *A. tridentata* were found under dense pine and juniper on midslope positions; and pine and juniper regeneration was noted in downslope positions where

evidence of previous tree occupancy was found.

Regeneration was largely associated with small draws, colluvial porcelanite, and shade from established trees.

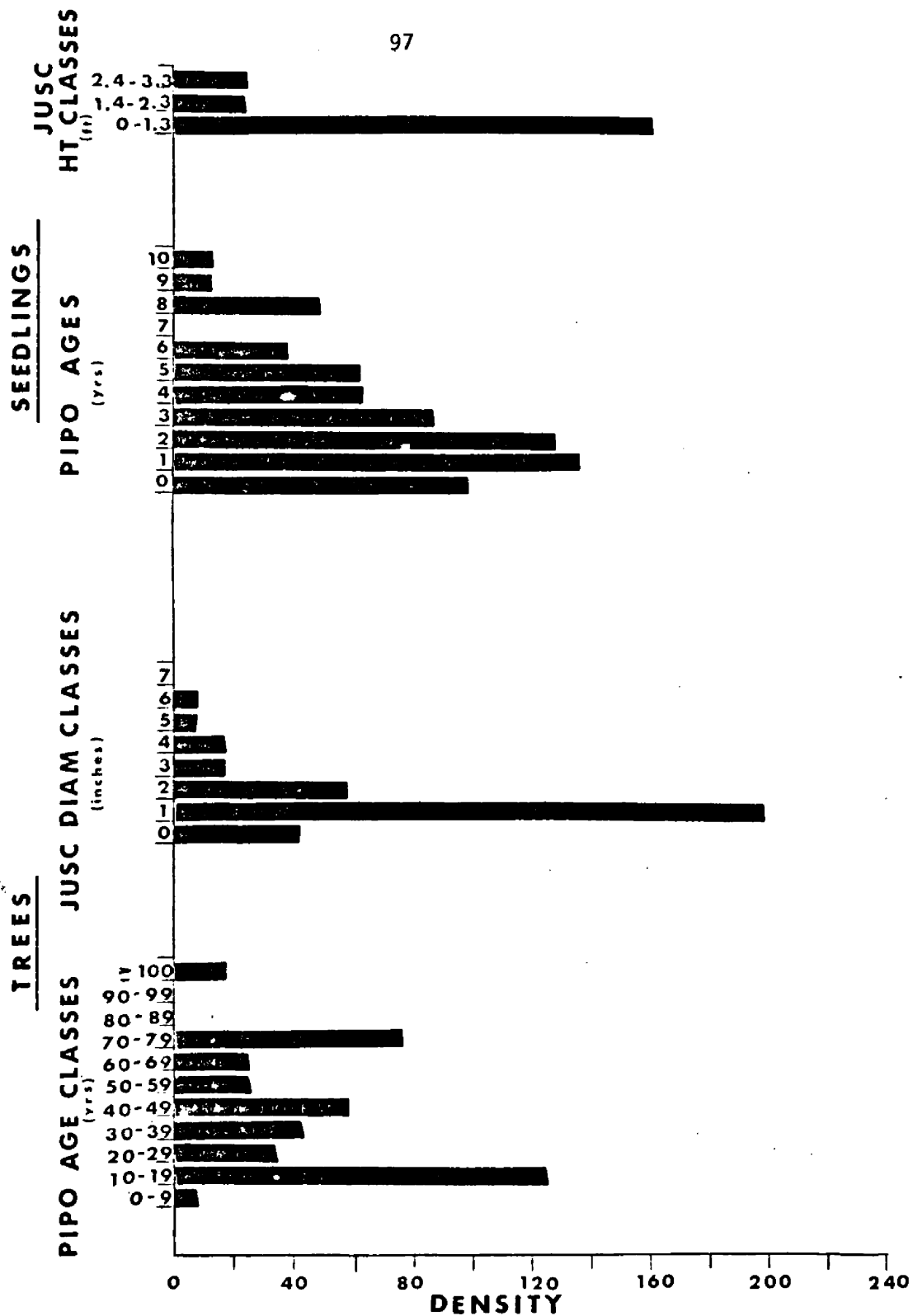


Figure 17. Structure of Stand 4. North slope densities (no./ha.) of seedlings and trees by age, height or diameter classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 5

Location: T2N, R42E, NW1/4, Sec. 30

Habitat Subtype: Ponderosa pine - Grassland (123)

Stand 5 occupied approximately 2 hectares on sandy rolling topography near an intermittent tributary of Cow Creek. Parent materials consisted of sandstone and baked sandstone. Slopes were very shallow (11%) and the maximum relief was twenty meters.

Stand 5 was unique in many ways. Very little bedrock was exposed at the surface. Soils were relatively deep and consisted of fine to medium sands and soft sandstones. Ponderosa pine exhibited high height/age ratios (.84 ft/year) and unlike other stands, showed little ring width sensitivity to drought cycles. Growth rates of five to six rings/inch were common, even throughout the 1930s. Apparently high water tables are maintained even through drought cycles.

The overstory consisted of open grown ponderosa pine (Density = 361/ha; B.A. =  $5.42 \text{ m}^2/\text{ha}$ .) most of which was younger than forty years old (see Figure A5). Rocky Mountain juniper has only recently invaded into the stand. The understory was comprised of diverse grass species dominated by *Stipa comata*, *Agropyron spicatum*, *A. smithii*, and *Koeleria cristata*.

Ponderosa pine regeneration was very dense (1219/ha.) and was largely limited to areas shaded by established trees. The average reduction of solar radiation on seedlings was forty-three percent. The lack of bare mineral soil and grass competition (averaging 42%

cover within a one foot circle of seedlings) did not impede establishment in this stand.

Only one fire scar was found and the oldest tree was eighty-nine years old. Therefore, the fire frequency was 1/89 years/2 ha.

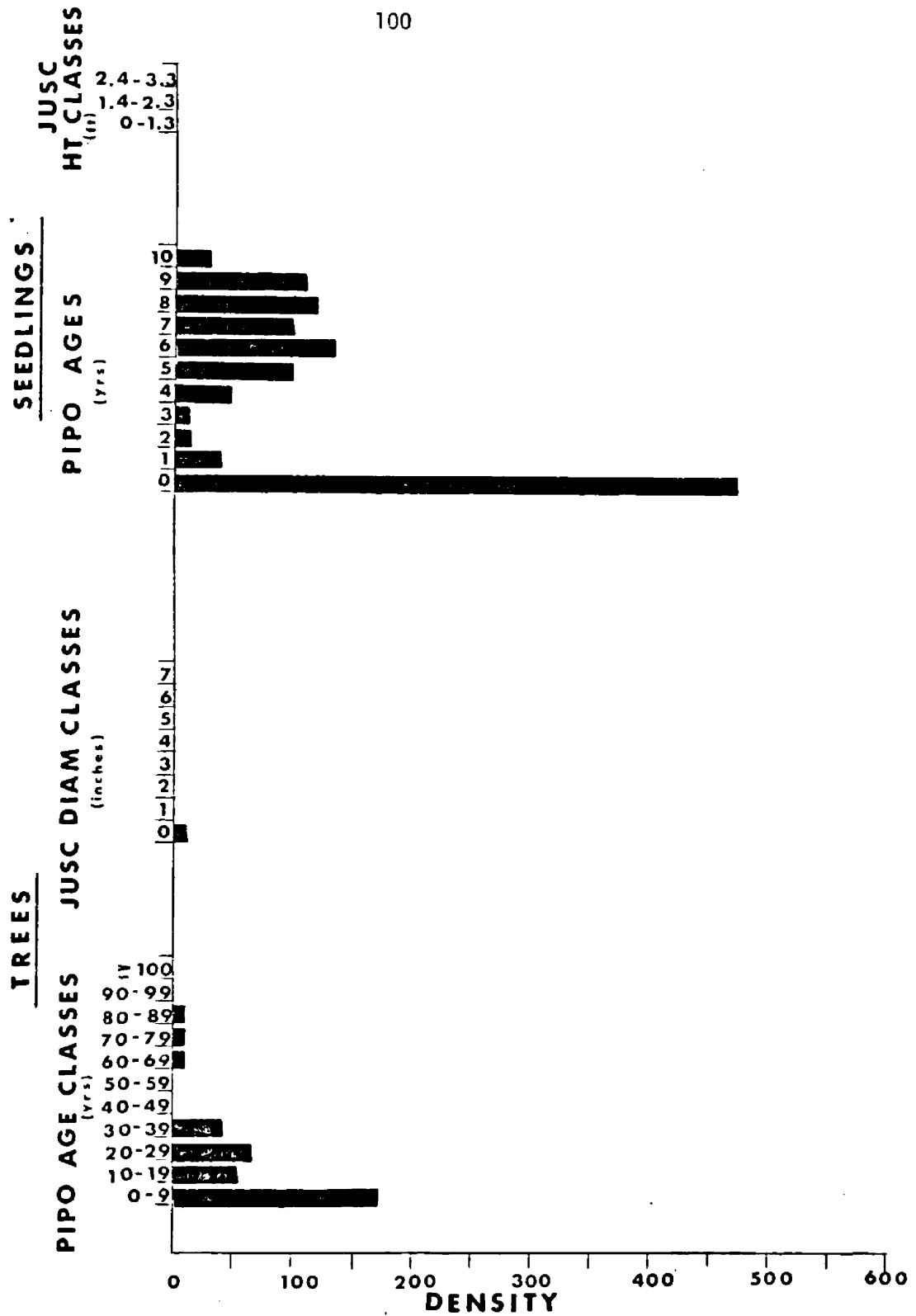


Figure 18. Structure of Stand 5. Total stand densities (no./ha.) of seedlings and trees by age, height or diameter classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.



## Stand 6

Location: T2N, R41E, NW1/4, Sec. 31

Vegetation Subtype: Ponderosa pine - Juniper (122)

Stand 6 occupied 1.5 hectares on a ridge spur that was flanked on both sides by a forked intermittent tributary of Stocker's Creek. Parent materials were sandstone and porcelanite (cap rock). Maximum relief was eighteen meters and both north and south facing slopes were very steep (42% and 50%, respectively).

Ponderosa pine and juniper were dense and often suppressed on the north slope (700/ha. and 225/ha., respectively). In midslope and upperslope positions the overstory canopy was nearly closed and understory vegetation consisted of decadent scattered shrubs (*Rhus trilobata*, *Symphoricarpos occidentalis* and *Artemisia tridentata*). Light attenuation and thick pine needle litter accumulation (~ 4") probably prevented the establishment of shrubs or grasses in the understory.

The south slope did not support conifers and was dominated by *Yucca glauca*. Slope steepness, erosion, calcareousness and the south-southwest exposure probably precluded tree establishment. The ridge top generally supported older, stunted ponderosa pines (one 12 foot tall, 5 in. d.b.h. pine was 103 years old) with an understory dominated by *Yucca glauca* and *Agropyron spicatum*.

Although no evidence of fires was found, the lack of trees between seventy and ninety-nine years old (see Figure A6) suggests that an intense fire may have occurred in the late 1800s or early 1900s.

Pine regeneration was more successful on the ridge top and in the *Pinus ponderosa*/*Artemisia tridentata* ecotone downslope of the stand. Juniper reproduction occurred even under the very dense portions of the stand.

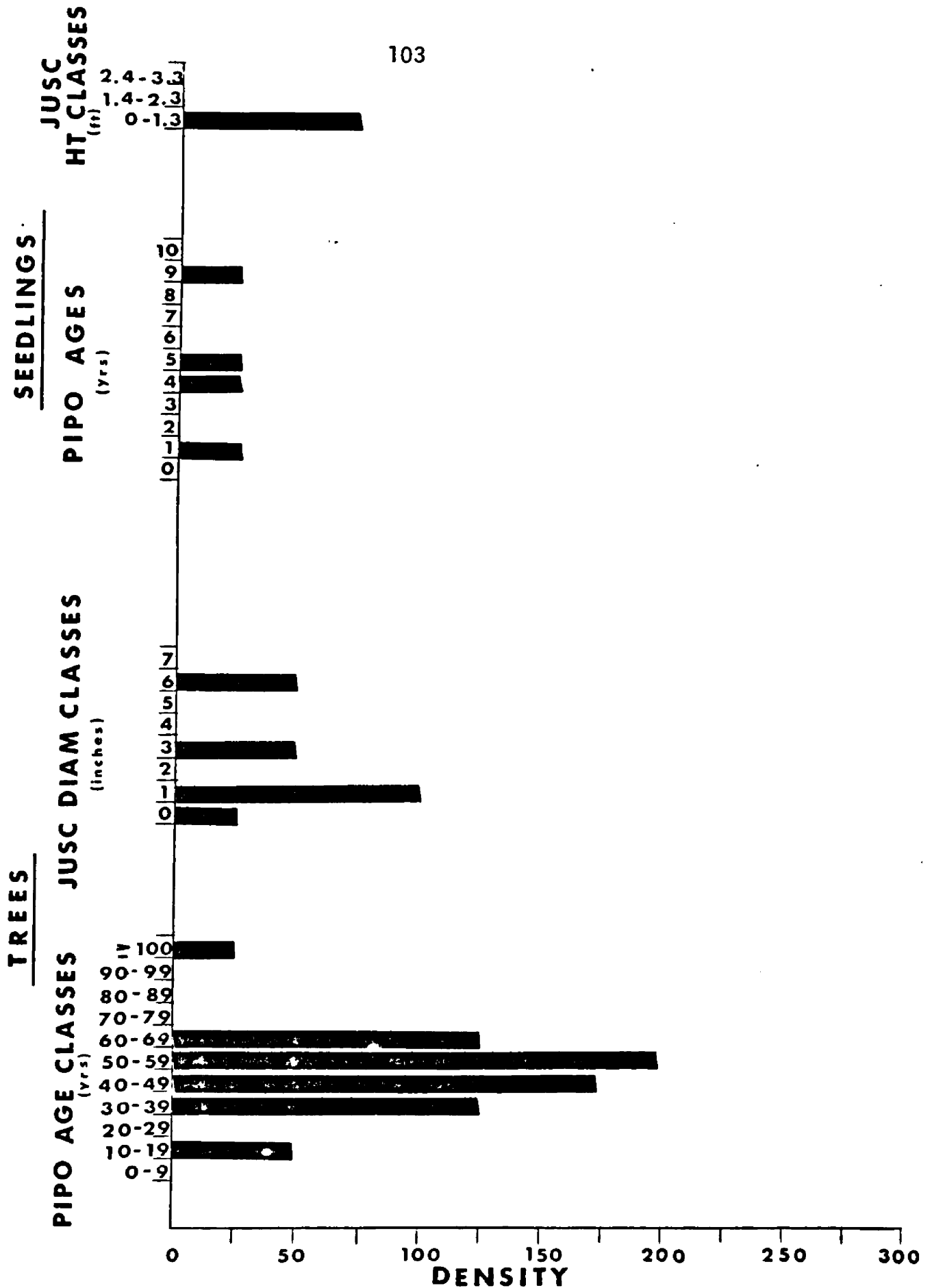


Figure 19. Structure of Stand 6. North slope and ridge densities (no./ha.) of seedlings and trees by age, height or diameter classes.

## Stand 7

Location: T1N, R40E, NW1/4, Sec. 13

Habitat Subtype: Ponderosa pine - Deciduous Shrub (124)

Stand 7 occupied 4.8 hectares on a gentle ridge of fine sandstone with a maximum relief of fifteen meters. Pines were associated with slopes or rock outcrops which encircled a small upland plateau dominated by mixed grasses and *Artemisia tridentata*.

Southern exposures were calcareous, rocky, erosive, and sparsely covered with *Rhus trilobata*, *Yucca glauca*, *Agropyron spicatum*, *Schizachyrium scoparium*, *Carex filifolia*, *Stipa comata* and diverse forb species. Gravel and sandy loam overlaid large clay pedes (> 6") at about six inches below the surface. Mass wasting was evident near the ridge top. Ponderosa pine density was lower than any other south facing sample area (38/ha.).

Northern exposures were floristically similar to southern exposures except for the addition of *Symphoricarpos occidentalis* and juniper. This exposure differed from the southern exposure in that pine density (121/ha.) and grass cover were greater; it was not calcareous, and ponderosa pine regeneration was prolific (1413/ha.).

No evidence of fire was found on the south slope, whereas at least one small fire occurred on the north slope within the last ninety years (1960). However, the lack of pines in the thirty to seventy year age classes (see Figure A7) suggests that low-intensity fires may have occurred previously.

Regeneration on southern exposures was minimal. Two types of microsites supported regeneration: small sandstone outcrops, and surface sandstone gravels similar to the desert pavement described by Springer (1958). Juniper was just beginning to establish on the south slopes (Figure A7).

The pine regeneration on the north exposure was associated with unique microsites. Most of the ponderosa pine seedlings were establishing in shallow depressions which form when erosion removes soil downslope from clump grasses and some species of forbs (e.g. *Phlox hoodii*). Many of these "microtroughs" supported regeneration, perhaps by providing small water-receiving areas (see Figure 6C).

Another unusual pattern of regeneration occurred where *Juniperus horizontalis* formed a large patch of complete ground cover. In this area, ponderosa pine was almost exclusively limited to the confines of the juniper patch (see Figure 6E). The juniper occupied a north facing slope berm and perhaps reduced evapotranspiration, thereby providing more moisture for establishing pine seedlings. The seedlings in this area were not aged, but appeared to be very vigorous.

The north facing ponderosa pine seedlings on Stand 7 had the greatest height/age ratio (.42 ft./year) of any seedlings measured; the mature trees exhibited only average growth. Thus, the microsites described above were superior to many others in terms of rapid early growth. Moreover, judging from the seedling age-class distribution (Figure A7), These microsites provide continual advantages for establishment regardless of macroclimatic fluctuations in the region.

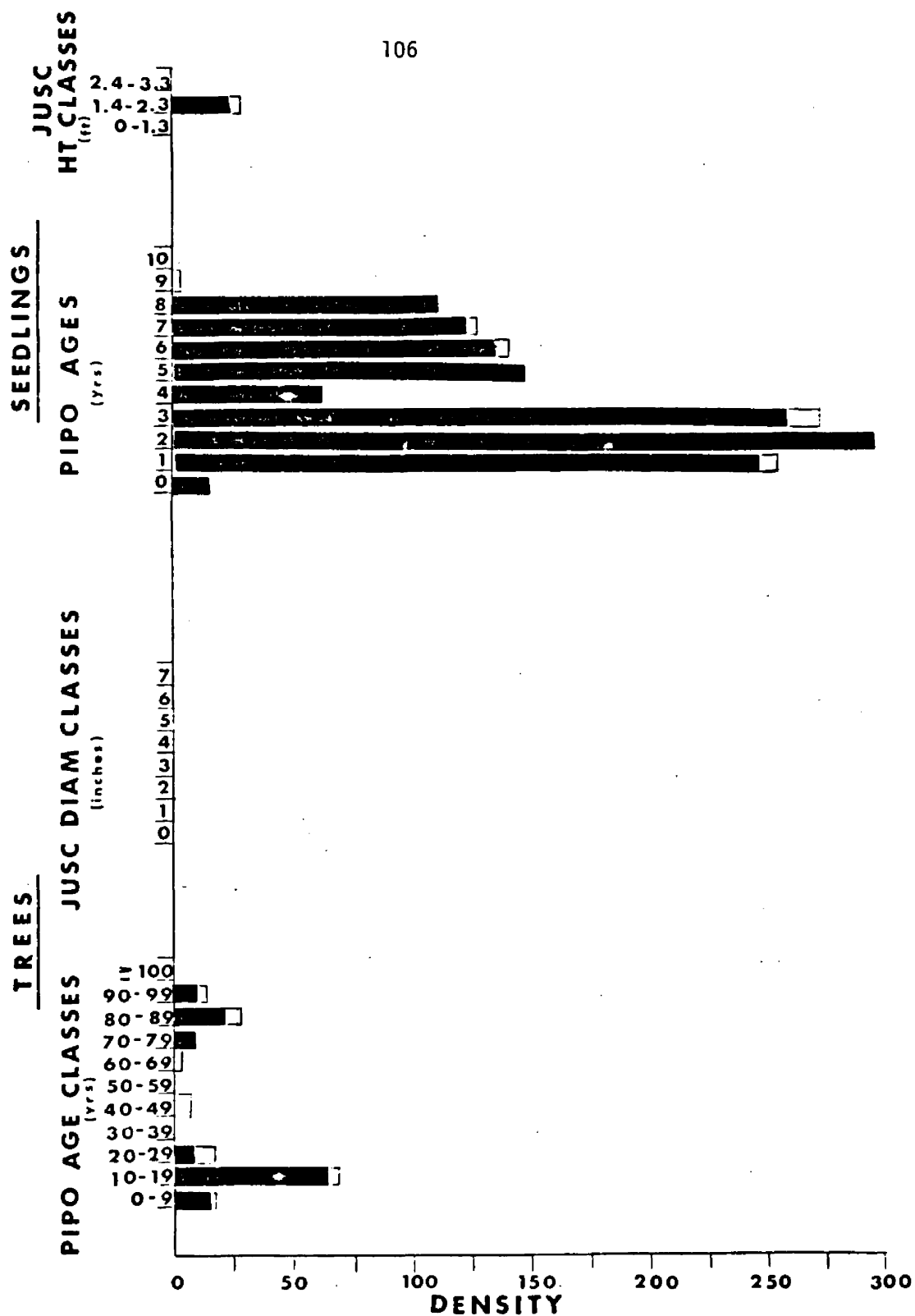


Figure 20. Structure of Stand 7. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of trees and seedlings by age, diameter or height classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 8

Location: T2N, R40E, SW1/4, Sec. 36

Vegetation Subtype: Ponderosa pine - Deciduous Shrub (124)

Stand 8 occupied 3.1 hectares on a shallow ridgeline with maximum relief of less than ten meters. Stand 8 was actually a portion of a larger, discontinuous stand that occupied most of the southern half of Section 36. Parent material was sandstone.

The south slope was dominated by ponderosa pine (Density = 167/ha.; B.A. =  $8.50 \text{ m}^2/\text{ha.}$ ) with an understory of *Rhus trilobata*, *Yucca glauca*, *Agropyron spicatum*, *A. smithii*, *Schizachyrium scoparium*, and *Carex filifolia*. Exposed soil surfaces were only slightly calcareous. No evidence of fire was found on the south slope in the last 98 years. Basal area was the highest measured for any south-facing area.

The north slope supported dense ponderosa pine (Density = 733/ha.; B.A. =  $18.03 \text{ m}^2/\text{ha.}$ ), young junipers, and diverse shrub, graminoid and forb species, dominated by *Symphoricarpos occidentalis*, *Agropyron smithii*, *A. spicatum*, and *Carex pennsylvanica*. Suppressed trees and senescent *Symphoricarpos occidentalis* were common in very dense areas on the north slope; although the highest overall height/age tree ratios were found on this transect (0.84 ft./year).

At least two fires have swept through the stand since its establishment. An old relic tree established in 1792 survived a fire in 1810, and part of the stand burned in 1965. Thus the fire frequency was 2 fires/188 years/3.1 hectares. This was generally reflected in the all-aged distribution of pines on the north slope (see Figure A8).

South slope regeneration was limited to ponderosa pine (183/ha.) and was associated with shaded sandstone outcrops. North slope regeneration included both juniper and pine (163/ha. and 1400/ha., respectively). Numerous seedlings were establishing under dense overstory conditions in a 2-3" litter layer. The seedling age-class distribution (Figure A8) and observations of several dead young seedlings indicate that mortality is quite severe after two growing seasons. In contrast, juniper regeneration appeared to be more successful under such conditions.



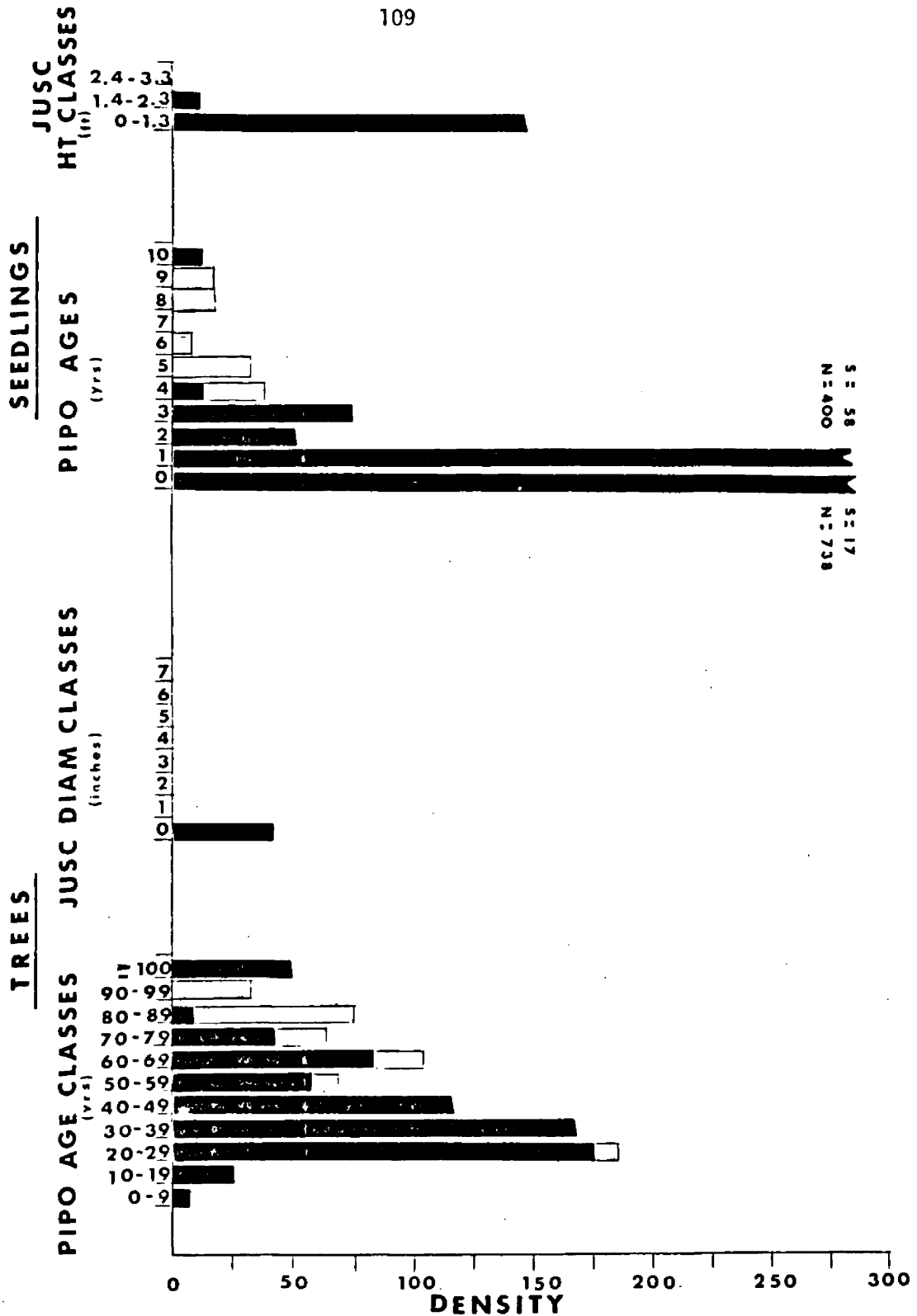


Figure 21. Structure of Stand 8. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of trees and seedlings by diameter, age or height classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 9

Location: T2N, R40E, SW1/4, Sec. 35

Vegetation Subtype: Ponderosa pine - Deciduous Shrub (124)

Stand 9 occupied 2.2 hectares on a ridge spur that trended to the southeast and formed a gently sloped amphitheater. Parent material consisted of sandstone; maximum relief was 21 meters. Surface soil was not calcareous.

Southern exposures supported pine savanna (cover = 20%, density = 100/ha.; B.A. =  $4.06 \text{ m}^2/\text{ha.}$ ), *Rhus trilobata*, *Yucca glauca*, *Bouteloua gracilis*, *B. curtipendula*, *Stipa comata*, *Agropyron spicatum*, and many other grass species. Surface soil was not calcareous and twenty percent of the area had exposed sandstone. Ponderosa pine was concentrated in the upper slope positions and integrated into *Rhus trilobata* dominated grasslands on lower slopes. A small fire penetrated part of the stand in 1960; no evidence of other fires was found on the south exposure.

The north slope supported higher density ponderosa pine (cover = 40%; density = 817/ha.; B.A. =  $14.92 \text{ m}^2/\text{ha.}$ ), and more diverse shrub and forb species (including *Symphoricarpos occidentalis*). Graminoids were dominated by *Agropyron spicatum* and *Carex pennsylvanica*. Rocky Mountain juniper was becoming established (density = 50/ha.). Three fire scars were dated from 1929, 1959 and 1964, although the location of the scarred trees suggests that the fires were highly localized.

The all-age class distribution of ponderosa pine trees (see Figure A9) indicates fire was relatively unimportant in influencing the

the stand structure on either exposure. Some pole-size logs had been cut from the north slope (~ 6 stumps), but not enough to have significantly influenced stand structure.

Natural regeneration was not too successful on either exposure. ON the southern exposure seedlings were establishing in partial shade in upper slope positions (150/ha.). North slope regeneration (175/ha.) was frequently suppressed and was largely limited to upper slope rock outcrop areas. Juniper was reproducing successfully on the north slope.

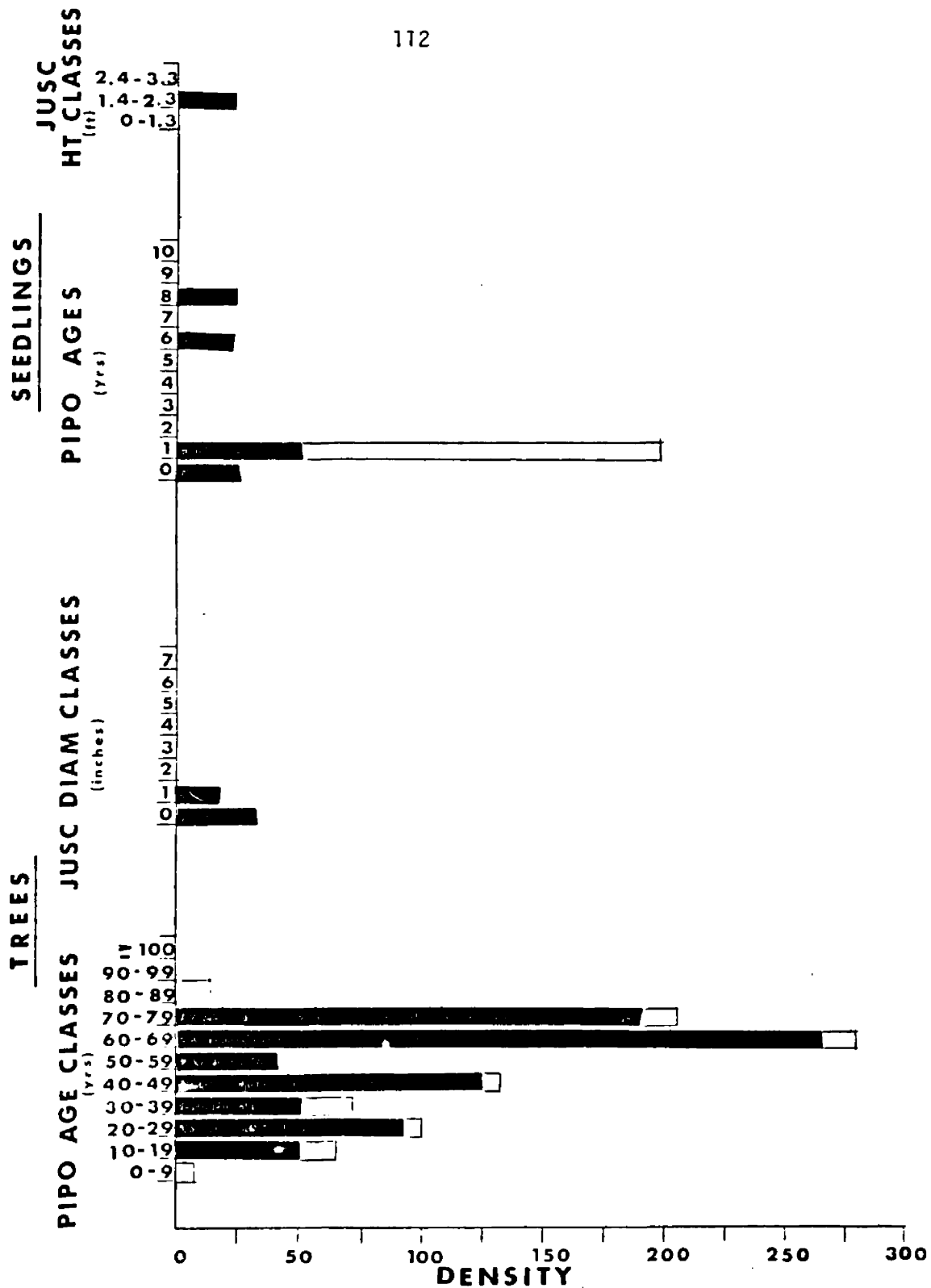


Figure 22. Structure of Stand 9. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of trees and seedlings by diameter, age or height classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 10

Location: T1N, R40E, NE1/4, Sec. 1

Habitat Subtype: Ponderosa pine - Deciduous Shrub (124)

Stand 10 occupied 4.6 hectares on a gently spur with sandstone and vitrified shale parent materials. Stand 10 was very similar to Stand 8 and the two could actually be considered as parts of the same stand except that they were separated by topographic discontinuities. Maximum relief was fifteen meters and neither exposure had calcareous surface soils.

Stand 10 supported nearly as much tree basal area as Stand 8 (13.94 and 13.16 m<sup>2</sup>/ha., respectively). Overall tree density was higher than any other stand (1447/ha.).

Southern exposures supported all-aged ponderosa pine (B.A. = 6.68 m<sup>2</sup>/ha.; density = 411/ha.; cover = 30%) and a trace of Rocky Mountain juniper. *Rhus trilobata*, *Yucca glauca*, and *Artemisia cana* were the dominant shrub species. Diverse forb and graminoid species were dominated by *Bouteloua gracilis*, *Agropyron spicatum*, and *Stipa comata*. The midslope to upper slope pine dominated area integrated into an *Artemisia cana* - *Xanthocephalum sarothrae* - mixed grass community downslope. Several pines were suppressed.

Northern exposures supported extremely dense pine (density = 2367/ha.; B.A. = 19.58 m<sup>2</sup>/ha.; cover = 70%) and Rocky Mountain juniper (density = 100/ha.; B.A. = 0.05 m<sup>2</sup>/ha.). Although the age class distribution was all-aged (see Figure A10), most trees established after 1930 were very suppressed. Understory cover was very sparse; *Juniperus*

*horizontalis*, *Symphoricarpos occidentalis*, and *Agropyron spicatum* were dominant species. Senescent *Rhus trilobata* and *Artemisia cana* were also present.

Two fires occurred in the eastern portion of the stand in 1925 and 1938. A shallow but extensive sandstone outcrop may have prevented the fires from extending into the rest of the stand. A large (d.b.h. = 27"); age = 173 years old) relic pine along the south transect had a fire scar from 1855. Low intensity fires probably burned in the area more often than fire scar evidence suggests. The fires may have killed young pines without rescarring the relic tree and would thus explain the lack of any other trees greater than 89 years old on the south transect.

Unlike other stands, regeneration was greater on the south slope (pine = 1142/ha.; juniper = 100/ha.) than on the north slope (pine = 433/ha.; juniper = 67/ha.). South slope regeneration was greatest where partial shade (averaging 26% of direct sunlight) and surface sandstone existed. North slope regeneration only occurred in small openings or where rocks were exposed. First and second year pine seedlings were found under full shade in 2-3 inches of pine litter.

Height/age ratio comparisons indicate suppressed conditions on the north versus south transects. North slope pine trees and seedlings averaged 0.52 feet/year and 0.20 feet/year, respectively, whereas south slope pine trees and seedlings averaged 0.82 feet/year and 0.25 feet/year, respectively.

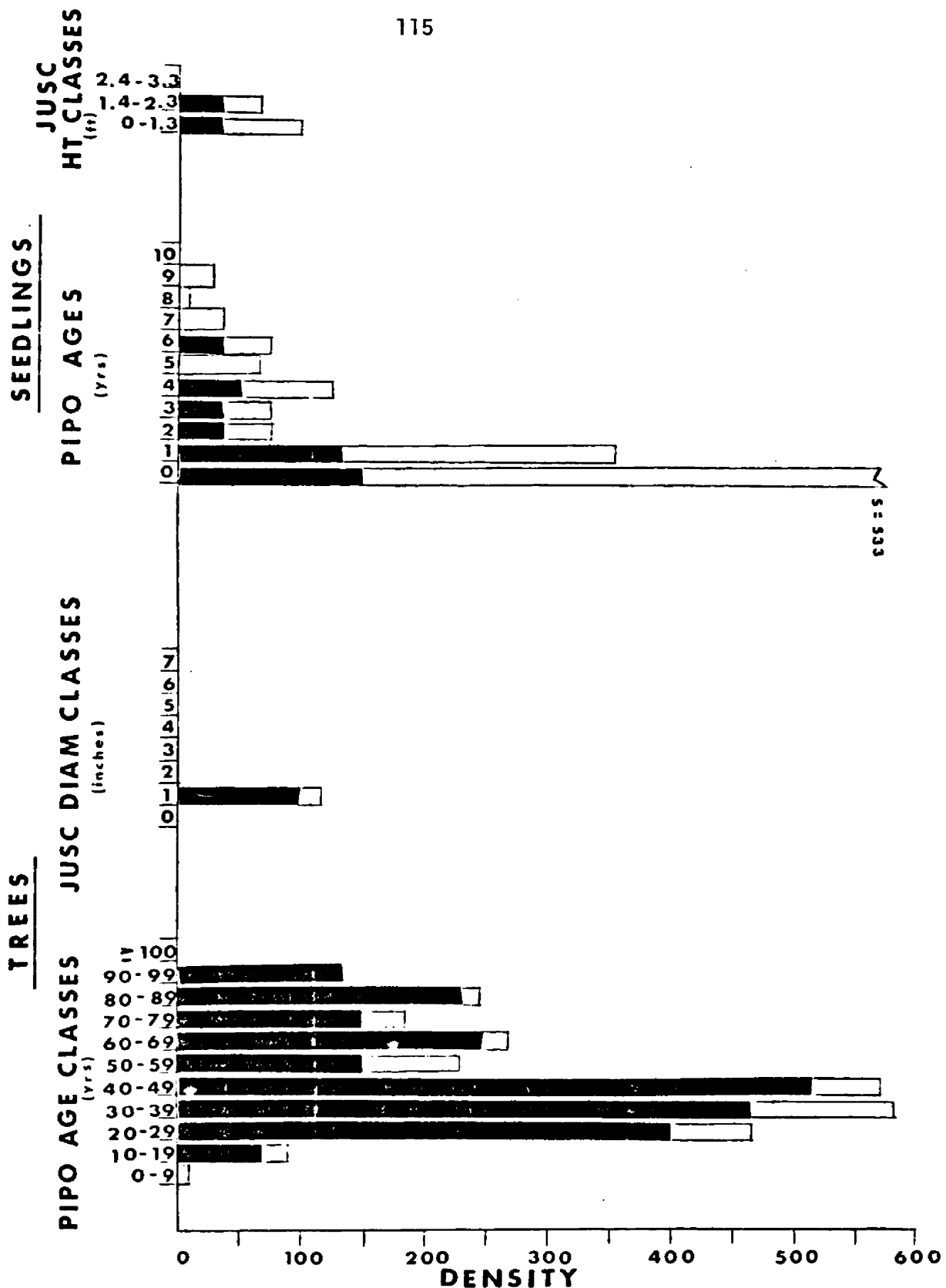


Figure 23. Structure of Stand 10. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of trees and seedlings by age, height or diameter classes. Note: "trees" are >1 meter tall; seedlings are ≤1 meter tall.

## Stand 11

Location: T1N, R41E, SW1/4, Sec. 17

Vegetation Subtype: Ponderosa pine - Deciduous Shrub (124)

Stand 11 occupied 2.8 hectares on a sandstone spur ridge extending to the east from an upland plateau. The maximum relief was twenty-four meters. Some portions of both the north and south slopes were calcareous.

Ponderosa pine dominated the overstory on the south slope (cover = 25%; density = 633/ha.; B.A. =  $13.47 \text{ m}^2/\text{ha.}$ ), but some Rocky Mountain juniper was also present (density = 133/ha.). *Rhus trilobata*, *Yucca glauca* and *Artemisia cana* were the dominant shrub species. Several grass and forb species were present but were dominated by *Schizachyrium scoparium* and *Agropyron spicatum*.

The north slope supported higher densities of both pine and juniper (633/ha. and 133/ha., respectively). Understory vegetation was similar to the south slope except for the presence of *Symphoricarpos occidentalis* instead of *Yucca glauca*, and increased cover of *Agropyron spicatum*.

No fire scars were found on either exposure, although a charred log on the north slope indicated a fire had occurred within the last century. The age-class structure (see Figure A11) was all-aged although very few trees became established in the 1960s.

Regeneration densities were sharply contrasted between the north and the south slopes. What little regeneration occurred on the south slope (pine density = 33/ha; juniper density = 8/ha.) was associated with rocky, shaded, water-catchment areas. The north slope supported



the greatest density of seedlings of all sampled stands (pine density = 2700/ha.; juniper = 217/ha.). Two types of microsite conditions contributed to the high seedling density; small mesic draws and exposed sandstone rocks. Grass competition and the lack of bare mineral soil did not hinder establishment. On the north slope ponderosa pine seedlings established in every year in the last decade except 1972 (see Figure A11); south slope seedlings only established in 1974, 1975, and 1977.

Height/age ratios of north slope pine seedlings and trees (0.3 feet/year and 0.65 feet/year, respectively) were greater than south slope pine seedlings and trees (0.60 feet/year and 0.2 feet/year, respectively).

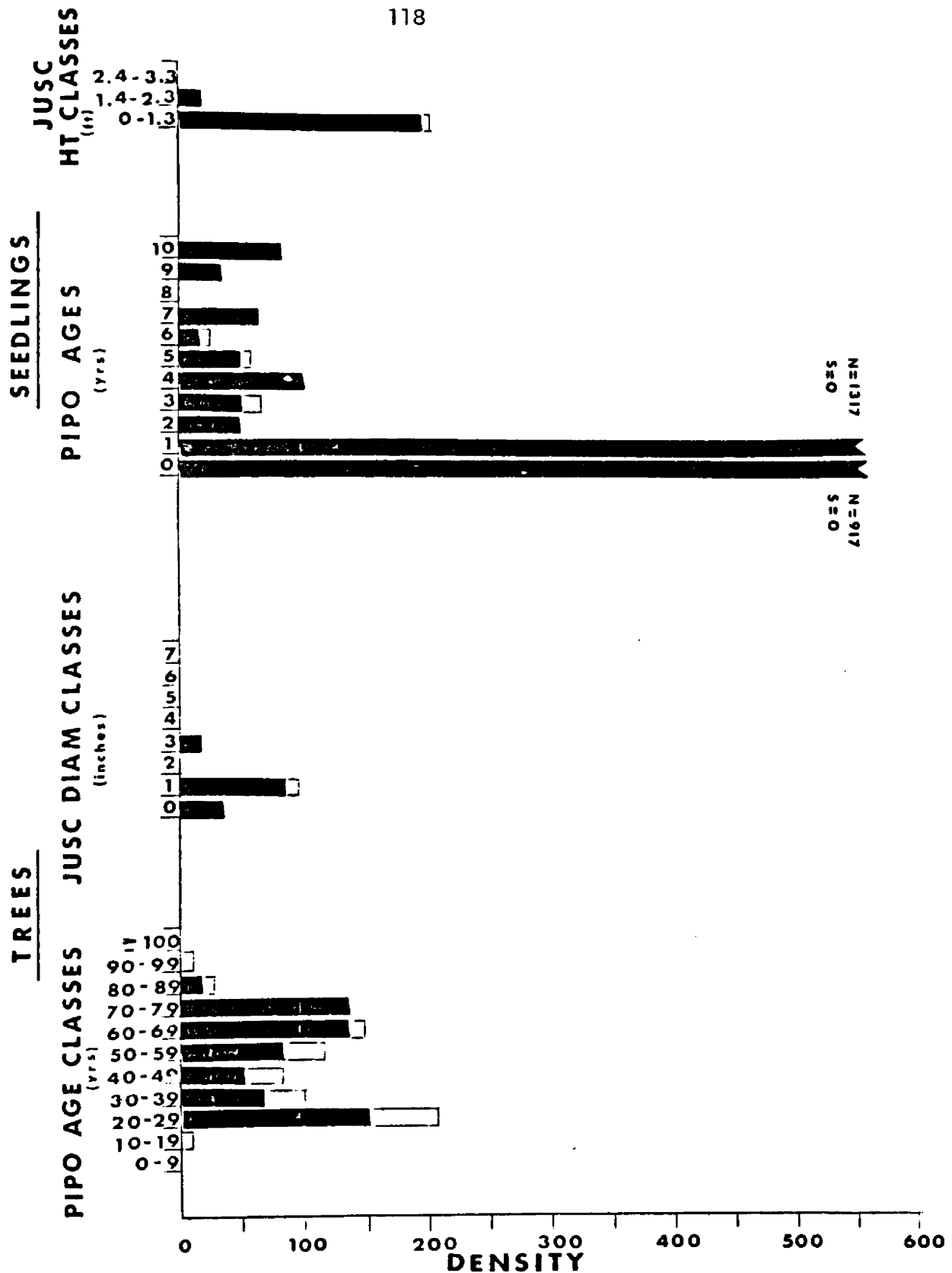


Figure 24. Structure of Stand 11. Continuous bar graphs show north (solid bars) and south (open bars) slope densities (no./ha.) of trees and seedlings by age, diameter or height classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## Stand 12

Location: T1N, R42E, NW1/4, Sec. 18

Stand 12 was situated in a massive sandstone outcrop with undulating topography. Soil and vegetation were nearly lacking except along the perimeter of the outcrop. Ponderosa pine was largely limited to the outcrop; Rocky Mountain juniper, *Artemisia tridentata*, *Rhus trilobata* and *Agropyron spicatum* dominated the adjacent area.

Densities of ponderosa pine and juniper were low (122/ha. and 36/ha., respectively). Regeneration of ponderosa pine was prolific (1013/ha.) in sandy water catchments and in massive sandstone fissures. Juniper was only reproducing in more developed soils.

Height/age ratios were very low in Stand 12. Ponderosa pine trees averaged only 0.3 feet/year; seedlings averaged 0.2 feet/year. Growth is probably limited by the small area in which root systems can expand. Thus, the same microsites which favor early survival provide limited potential for growth and may preclude long term survival.

The age-class distribution of ponderosa pine (see Figure A12) was uneven-aged with a lack of trees in the thirty to fifty-nine year age classes. Remains of an early homesteader's cabin on the site suggest that human use may have influenced stand structure substantially; no cut stumps were found, however, regeneration may have been adversely affected by human occupancy.

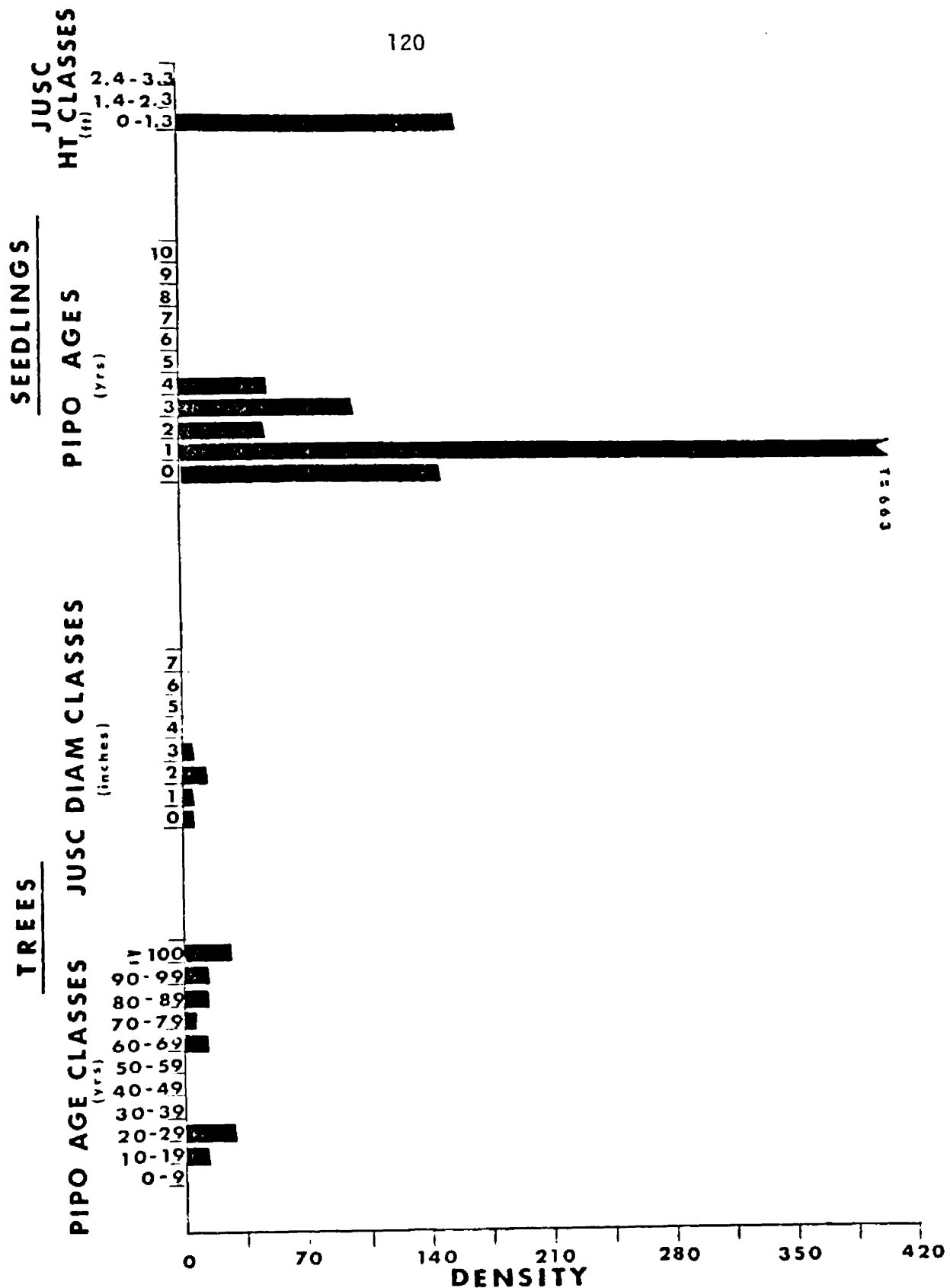


Figure 25. Structure of Stand 12. Total stand densities (no./ha.) of seedlings and trees by age, height or diameter classes. Note: "trees" are >1 meter tall; "seedlings" are ≤1 meter tall.

## APPENDIX B

Means and standard errors of basal area and density estimates on each transect and stand.

Appendix B Means and standard errors of basal area and density estimates on each transect and stand.

Stand	Transect	TREES						SEEDLINGS		
		Basal Area (M <sup>2</sup> /Hectare)			#/Hectare			#/Hectare		
		PIPO (s.e.)	JUSC (s.e.)	TOTAL (s.e.)	PIPO (s.e.)	JUSC (s.e.)	TOTAL (s.e.)	PIPO (s.e.)	JUSC (s.e.)	TOTAL (s.e.)
1	S	1.32(0.55)	0.00 -	1.32(0.55)	65(17)	0(0)	65(17)	50(25)	0 -	50(25)
	N	0.47(0.28)	0.03(0.02)	0.49(0.29)	151(124)	19(14)	170(138)	169(86)	113(113)	281(175)
	T	0.89(0.33)	0.12(0.01)	0.90(0.33)	108(60)	9(8)	118(67)	109(46)	56(56)	166(91)
2	S	1.49(0.42)	0.00 -	1.49(0.42)	57(23)	0 -	57(23)	119(50)	0 -	119(50)
	N	4.18(1.30)	0.11(0.09)	4.29(1.27)	383(67)	58(29)	442(46)	200(46)	450(394)	650(424)
	T	2.83(0.81)	0.06(0.05)	2.89(0.82)	220(70)	29(17)	249(76)	159(35)	225(199)	384(218)
3	S	1.20(0.43)	0.00 -	1.20(0.43)	57(25)	0 -	57(25)	31(21)	0 -	31(21)
	N	13.13(2.76)	0.00 -	13.13(2.76)	230(64)	0 -	230(64)	156(76)	0 -	156(76)
	T	7.17(2.60)	0.00 -	7.17(2.60)	144(46)	0 -	144(46)	94(42)	0 -	94(42)
4	N	7.57(2.59)	0.69(0.33)	8.26(2.49)	408(96)	350(242)	758(227)	700(304)	213(79)	913(340)
5	T	5.42(1.88)	0.00 -	5.42(1.88)	361(212)	8(8)	369(208)	1219(537)	0 -	1219(536)
6	N	13.00(2.05)	1.19(1.19)	14.19(3.24)	700(200)	225(175)	925(375)	100(41)	75(48)	175(48)
7	S	2.04(1.57)	0.00 -	2.04(1.57)	38(14)	0 -	38(14)	38(15)	4(4)	42(16)
	N	3.24(0.56)	0.00 -	3.24(0.56)	121(36)	0 -	121(36)	1413(419)	25(25)	1438(433)
	T	2.34(1.17)	0.00 -	2.34(1.17)	59(18)	0 -	59(18)	381(180)	9(7)	391(184)
8	S	8.50(0.81)	0.00 -	8.50(0.81)	167(19)	0 -	167(19)	183(46)	0 -	183(46)
	N	18.03(6.73)	0.00 -	18.03(6.73)	733(225)	42(21)	775(246)	1400(769)	163(80)	1563(839)
	T	13.94(4.09)	0.00 -	13.94(4.09)	491(166)	24(14)	514(180)	879(458)	93(50)	971(503)
9	S	4.06(1.36)	0.00 -	4.06(1.36)	100(14)	0 -	100(14)	150(150)	0 -	150(150)
	N	14.92(1.55)	0.01(0.01)	14.93(1.55)	817(17)	50(50)	867(67)	175(103)	25(25)	200(91)
	T	9.49(3.25)	0.00 -	9.49(3.25)	458(207)	25(25)	483(223)	163(84)	13(13)	175(82)
10	S	6.68(0.83)	0.01(0.01)	6.69(0.88)	411(48)	17(17)	428(64)	1142(596)	100(100)	1242(686)
	N	19.58(6.25)	0.05(0.03)	19.63(6.28)	2367(970)	100(58)	2467(1039)	433(203)	67(33)	500(198)
	T	13.13(4.04)	0.03(0.02)	13.16(4.05)	1389(616)	58(33)	1447(642)	788(318)	83(51)	871(359)
11	S	6.40(2.27)	0.01(0.01)	6.40(2.27)	200(19)	11(11)	211(29)	33(17)	8(8)	42(15)
	N	13.47(3.00)	0.12(0.08)	13.59(2.89)	633(85)	133(17)	767(73)	2700(1145)	217(65)	2917(1196)
	T	9.93(2.30)	0.06(0.04)	9.99(2.30)	417(105)	72(29)	489(129)	1367(678)	113(44)	1479(716)
12	T	2.93(0.47)	0.07(0.07)	2.99(0.53)	122(7)	36(36)	157(43)	1013(800)	163(163)	1175(764)